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Relative values of criteria used in drawing the Ordovician-Silurian boundary. E. O. ULRICH†	279–348	....	....	.70	1.05
Santorini eruption of 1925. H. S. WASHINGTON	349–384	9–10	11	.40	.60
Permian vertebrates from West Virginia. J. L. TILTON†	385–396	11	2	.15	.25
New reconstruction of *Lasanius* G. G. SIMPSON†	397–402	....	1	.10	.15
Intrusive granite of the Rose Dome, Woodson County, Kansas. W. H. TWENHOFEL	403–412	....	2	.10	.15
Guadalupe group. N. H. DARTON and J. B. REESIDE, JR.	413–428	12–16	5	.30	.45
Upper Cretaceous shoreline in Utah. E. M. SPIEKER and J. B. REESIDE, JR.	429–438	....	3	.10	.15

* Preliminary pages and index are distributed with number 4.

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Hypothesis of mountain-building. E. C. Andrews	439–454	....	....	$0.15	$0.25
Reynosa formation in Lower Rio Grande region, Texas. A. C. Trowbridge	455–462	....	3	.10	.15
Ground-water problems on the barrier beaches of New Jersey. D. G. Thompson	463–474	....	6	.10	.15
Devonian volcanic rocks near Dalhousie, New Brunswick. W. V. Howard	475–496	....	2	.20	.30
Taconic folding in Pennsylvania. B. L. Miller	497–512	....	....	.15	.25
Silurian rocks of Illinois. T. E. Savage	513–534	....	1	.25	.40
Geology of the Mingan Islands. W. H. Twenhofel	535–550	....	3	.15	.25
Structural studies in southern Nevada and western Arizona. C. R. Longwell	551–584	17–20	7	.45	.65
Origin of California petroleum. F. M. Anderson	585–614	....	....	.30	.45
Pre-Cambrian geology of the Medicine Bow Mountains. E. Blackwelder	615–658	....	11	.45	.65

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 40 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

Regular Editions

Pages 261–278,		50	copies,	March	30, 1926.
" 279–348,*†		450	"	June	30, 1926.
" 349–384,	plates 9–10,	750	"	"	30, 1926.
" 385–396,*†	plate 11,	350	"	"	30, 1926.
" 397–402,*†		300	"	"	30, 1926.
" 403–412,		110	"	"	30, 1926.
" 413–428,	plates 12–16,	90	"	September	30, 1926.
" 429–438,		90	"	"	30, 1926.
" 439–454,		150	"	"	30, 1926.
" 455–462,		100	"	"	30, 1926.
" 463–474,		75	"	"	30, 1926.
" 475–496,		400	"	"	30, 1926.
" 497–512,		110	"	"	30, 1926.
" 513–534,		150	"	December	30, 1926.
" 535–550,		110	"	"	30, 1926.
" 551–584,	plates 17–20,	125	"	"	30, 1926.
" 585–614,		90	"	"	30, 1926.
" 615–658,		350	"	"	30, 1926.

Special Editions ‡

Pages 15– 48,	plate 1,	50	copies,	March	30, 1926.
" 49– 93,	" 2,	350	"	"	30, 1926.
" 94– 96,	" 3,	85	"	"	30, 1926.
" 96– 99,	" 4,	50	"	"	30, 1926.
" 99–110,	" 5,	50	"	"	30, 1926.
" 111–114,	" 6,	50	"	"	30, 1926.
" 115–134,	" 7,	550	"	"	30, 1926.
" 134–141,	" 8,	50	"	"	30, 1926.
" 161,		50	"	"	30, 1926.
" 191–206,		200	"	"	30, 1926.
" 207–224,		50	"	"	30, 1926.
" 225–254,*†		200	"	"	30, 1926.
" 255–260,		50	"	"	30, 1926.

* Bearing on the cover
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.
[Reprinted from the Bulletin of the Geological Society of America, vol. ——, pp. ——, pls. ——, (Date).]

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

‡ Bearing imprint [From BULL. GEOL. SOC. AM., Vol. 36, 1924]

CORRECTIONS AND INSERTIONS

Contributors to volume 37 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 421, plate 14, *insert* following title: Views of Delaware Mountain formation.

" 468, third line from bottom, *transpose* "it" and "is" so that sentence will *read* * * * a few hundred feet of the ocean, is it not surprising, etc.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 37, PP. 1-206, PLS. 1-8 MARCH 30, 1926

PROCEEDINGS OF THE THIRTY-EIGHTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT NEW HAVEN, CONNECTICUT, MONDAY-WEDNESDAY, DECEMBER 28-30, 1925.

CHARLES P. BERKEY, *Secretary*

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SESSION OF MONDAY MORNING, DECEMBER 28

The Thirty-eighth Annual Meeting of the Geological Society of America was called to order in the Auditorium of Sterling Chemistry Laboratory, New Haven, Connecticut, at 9.05 a. m., by President Scott. Brief introductory remarks were made by the chairman, who called attention to the crowded condition of the program and asked cooperation in meeting the limited time schedule.

REPORT OF THE COUNCIL

The report of the Council was presented by Secretary Berkey, as follows:

To the Geological Society of America, in thirty-eighth annual meeting assembled:

The regular annual meeting of the Council was held at Ithaca, New York, in connection with the meeting of the Society, December 29-31, 1924. A special meeting was also held in New York City on October 10, 1925.

The details of administration for the thirty-seventh year of the existence of the Society are given in the following reports of the officers:

PRESIDENT'S REPORT

To the Council of the Geological Society of America:

The President's report for the year ending November 30, 1925, is as follows:

The Society continues in a condition of gratifying soundness and activity. The statistics of membership and of loss by death during the year are contained in the Secretary's report. The Treasurer's report shows the satisfactory condition of the Society's finances; and the work of publication, which is perhaps the Society's most important function, has been carried on despite the very great increase in the cost of printing and illustrations. The outlook for a long and promising career of usefulness to science is one of assured hope.

The organization of the program of papers at the meetings and the requirement of abstracts for all papers submitted, which was inaugurated two years ago, have been continued with gratifying results. In fact, the Society suffers somewhat from an embarrassment of riches, and finds difficulty in reserving a place on the program for all the meritorious papers that are offered.

The committees have, of necessity, done most of the work of admin-

istrative routine and detail; and for the current year the committees are as follows:

Membership Committee: W. H. Twenhofel, Chairman; David White, U. S. Grant.

Program Committee: Charles Schuchert, Chairman; James F. Kemp, Carl O. Dunbar, Frank R. Van Horn, R. S. Bassler, Alan M. Bateman, David White.

Committee on Foreign Correspondents: James F. Kemp, Chairman; Arthur P. Coleman, John M. Clarke (deceased), Douglas W. Johnson, Henry S. Washington.

Committee on Exchanges: Charles Schuchert, Chairman; Edward W. Berry, H. S. Washington.

Committee of Past-Presidents on the Presentation of Papers: James F. Kemp, Chairman; David White, Frank D. Adams.

Finance Committee: Fred. E. Wright, Joseph Stanley-Brown, R. A. F. Penrose, Jr.

Committee on Publication: James F. Kemp, Charles Schuchert, Joseph Stanley-Brown, Charles P. Berkey, Edward B. Mathews.

Local Committee for the New Haven Meeting: Alan M. Bateman, Chairman; William E. Ford, Herbert E. Gregory, Ellsworth Huntington, Adolph Knopf, Chester R. Longwell, Carl O. Dunbar, Malcolm R. Thorpe, Eleanora Bliss Knopf.

The Society has been represented by appointed delegates at various celebrations, as follows:

The Joseph A. Holmes Safety Association: Delegate, John J. Rutledge.
The Society of Economic Geologists: Delegate, James F. Kemp.
Fiftieth anniversary of the founding of George Peabody College for Teachers: Delegate, L. C. Glenn.
Institute of Politics: Delegate, H. Foster Bain.
Inauguration of John Martin Thomas as President of Rutgers University: Delegate, William B. Scott.
Semi-centennial of Vanderbilt University, and founding of the new plant and hospital of the School of Medicine: Delegate, Wilbur A. Nelson.

Respectfully submitted,

W. B. Scott,
President.

Secretary's Report

To the Council of the Geological Society of America:

The Secretary's annual report for the year ending November 30, 1925, is as follows:

Meetings.—The proceedings of the annual meeting of the Society, held at Ithaca, New York, December 29-31, 1924, have been recorded in volume 36, pages 1-198 of the Bulletin. Those of the Cordilleran Section, pages 199-210 of the Bulletin; of the Paleontological Society, pages 211-240; of the Mineralogical Society of America, pages 241-246 of the same volume.

Membership.—During the last year the Society has lost by death one Correspondent—Carlo de Stefani—and nine Fellows—John Mason Clarke, David T. Day, Richard R. Hice, William McInnes, Willet G. Miller, Frederick B. Peck, Henry H. Robinson, Gilbert van Ingen, and Jay B. Woodworth. The names of the seventeen candidates elected at the Ithaca meeting have been added to the printed list. There have been no names dropped from the list for non-payment of dues and no resignations. The present enrollment of the Society is 508. Thirteen candidates for Fellowship are before the Society for election, three for correspondentship, and a number of applications are under consideration by the Council.

Distribution of the Bulletin.—During the past year there have been sent out to domestic subscribers 164 copies and to foreign subscribers 69 copies of the Bulletin, 41 going to new subscribers. This shows an increase in subscriptions over last year of 34 copies. Eight volumes have been distributed gratis, as follows: Library of Congress, the Government Geological Surveys of the United States, Canada, Mexico, the Bureau of Science, Manila, Philippine Islands, the Smithsonian Institution, Washington, D. C., the Case Library, Cleveland, Ohio, and the Columbia University Library, New York City. The present exchange list comprises 51 addresses. The receipts of this office, including subscriptions to and sales of the Bulletin and separate brochures therefrom, are summarized as follows:

Detailed Financial Statement of the Secretary's Office

RECEIPTS

Regular subscriptions	$2,122.00
Irregular sales	1,974.66
Geological Magazine	117.30
Post and express refunds	94.82

Authors' separates and corrections	514.44
Exchange added to checks	1.75
Binding 1 copy Volume 35	4.00
1 copy Group Portrait	6.00
Telegram refund	.48
Total received and forwarded to Treasurer	$4,834.45

DISBURSEMENTS

On account of administration:

Printing expenses, Ithaca meeting		$264.00
Printing for 1925		101.05
Clerical help for 1925		400.00
Binding Volume 35 (3 copies)		12.50
Postage		128.28
Exchange on checks		5.70
Telegrams and telephone calls		7.66
Miscellaneous supplies		16.08
Cost of shipping 4 sets of Bulletin on foreign orders		73.50
Total		$1,008.77

On account of Bulletin:

5,250 clasp envelopes for Bulletin mailing		$57.18
Office expenses:		
Post and express charges	$77.89	
Carfare	1.20	
Telegrams	.84	
Addressograph plates	3.41	
Notary fees	1.00	
Miscellaneous	3.16	
		87.50
Total		$144.68

Respectfully submitted,

CHARLES P. BERKEY,
Secretary.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his report for the year ending November 30, 1925.

The membership of the Society on December 1, 1924, consisted of 394 paying annual dues, 90 Life Members, and 14 Correspondents. Seventeen new members qualified during the year. Two Life Members, 1 Cor-

respondent, and 7 Annual Members have died during the year. As the books close, the membership consists of 404 Annual Members (2 non-contributing), 88 Life Members, and 16 Correspondents, making a total of 508.

The fees receivable at the beginning and close of the year are as follows:

	Receivable Jan. 1, 1925	Collected to Nov. 30, 1925	Due Dec. 1, 1925
Fees of delinquents (1922, '23, '24)..	$300.00	$170.00	$110.00
Fees of 1925.....	4,110.00	3,816.60	220.00
Initiation fees (17).....	170.00	170.00	———
Prepayment of 1926 fees.....	.....	20.00	$330.00
	4,580.00	4,176.60	
Adjustments	50.00*	373.40†	
	$4,530.00	$4,550.00	
Less prepayments for 1926.....	.....	20.00	
		$4,530.00	

RECEIPTS

Cash on hand December 1, 1924.....		$3,559.56
Annual dues:		
From delinquents.....	$170.00	
For 1925 (381).....	3,810.00	
For 1925 balance due (1).....	3.60	
For 1926 (2).....	20.00	
		4,006.60
Initiation fees, 17 at $10.....		170.00
Gift of Charles Schuchert to Endowment Fund.....		100.00
Case Library.....		150.00
Redemption of bond:		
American Agricultural Chemical Co., called at 103.		1,030.00
Foreign exchange added to checks.....		.45
Interest:		
On investments.....	1,710.00	
On deposits.....	148.76	
		1,858.76
Received from Secretary:		
Bulletin sales.....	4,095.66	
Geological Magazine.....	117.30	
Author's separates and corrections.....	514.44	

*Written off for delinquencies..... $20.00
Written off for death..... 10.00
Written off for non-contributing..... 20.00
50.00

†Received prior to 1925..... 43.40
Present delinquency..... 330.00
$373.40

Exchange added to checks	1.75		
Postage and express refunds	94.82		
Miscellaneous	10.48		
		4,834.45	
			$15,709.82

DISBURSEMENTS

Secretary's office:			
Administration	$1,008.77		
Bulletin	144.68		
Portrait	5.00		
Geological Magazine	122.63		
Allowance	1,000.00		
		2,281.08	
Treasurer's office:			
Expenses	77.50		
Clerk	150.00		
		227.50	
Publication of Bulletin:			
Printing	5,166.70		
Engraving	734.69		
Paper	1,300.92		
Editor's allowance	250.00		
		7,452.31	
Mineralogical Society of America		111.00	
Cordilleran Section		80.00	
Purchase of rare Bulletins		131.00	
Investment:			
2 Central Railway Co. of Baltimore		2,000.00	
Accrued interest		8.33	
Exchange on foreign check		.25	
			$12,291.47
Balance in bank December 1, 1925			3,418.35
			$15,709.82

The Society holds securities yielding $1,710, with par value of $31,000, a book value of $30,244.25, and a market value estimated at $28,272.50.

Respectfully submitted,

EDWARD B. MATHEWS,
Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The following tables cover statistical data for the thirty-six volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost.	Average—Vols. 1-30.	Vol. 31.	Vol. 32.	Vol. 33.	Vol. 34.	Vol. 35.	Vol. 36.
	pp. 737. pls. 31.	pp. 468. pls. 14.	pp 506. pls. 12.	pp. 862. pls. 5.	pp. 778. pls. 20.	pp. 896. pls. 36.	pp. 707. pls. 10.
Letter press	$1,776.16	$1,541.45	$1,883 18	$3,006.32	$2,572.34	$4,048.05	$2,737.89
Illustrations	433.34	131.94	272.44	616.01	499.36	768.86	528.90
Paper	428.12	266.64	792.00	686.81	424.87	570.62	411.96
Total	$2,566.03	$1,940.03	$2,947.62	$4,309.14	$3,496.57	$5,387.53	$3,678.75
Average per page	$3.51	$4.15	$5.83	$5.00	$4.62	$5.84	$5.06

CLASSIFICATION OF SUBJECT-MATTER

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of Pages.											
1	116	137	92	18	83	44	47	...	60	4	4	593+xii
2	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3	56	41	44	41	32	158	104	...	61	15	1	541+xii
4	25	134	38	74	52	52	14	...	47	32	2	458+xii
5	138	135	70	54	28	51	107	...	71	14	9	665+xii
6	50	111	75	39	71	99	1	...	63	25	4	538+x
7	38	77	105	53	40	21	123	4	66	28	13	558+x
8	34	50	98	5	43	67	58	14	79	8	...	446+x
9	2	102	138	...	44	28	64	16	64	12	...	460+x
10	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	...	538+xi
13	125	17	13	24	28	116	42	4	165	32	29	583+xii
14	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	...	...	77	17	3	636+x
16	64	111	78	30	102	141	19	...	67	22	15	636+xiii
17	49	161	41	84	47	294	27	...	71	9	2	785+xiv
18	16	164	141	5	29	246	5	...	68	40	3	717+xii
19	106	108	29	66	30	155	32	...	56	15	20	617+x
20	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22	23	54	28	28	23	403	74	...	63	49	1	747+xii
23	75	52	126	108	19	145	134	...	66	32	1	758+xvi
24	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25	34	211	54	32	156	9	175	...	108	9	22	802+xviii
26	...	72	23	11	56	90	148	...	54	44	6	504+xxi
27	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28	25	273	70	69	78	200	55	39	94	110	14	1005+xxii
29	3	107	62	15	127	169	64	...	73	57	21	679+xix
30	160	3	41	9	5	36	205	16	73	59	50	644+xiii
31	1	80	19	4	13	45	22	21	69	97	79	450+xviii
32	73	47	7	27	63	51	77	17	105	2	37	488+xviii
33	39	166	160	47	97	107	101	3	91	41	31	862+xxi
34	20	256	73	2	39	149	48	...	89	38	64	778+xx
35	44	72	17	83	70	140	269	...	76	46	79	896+xxii
36	26	112	27	59	108	103	77	1	74	116	4	707+xx

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

The foregoing report is respectfully submitted.

THE COUNCIL.

December 28, 1925.

ELECTION OF AUDITING COMMITTEE

The printed report of the Council was distributed to all members in attendance. Since the report of the Council contains the Treasurer's report, it was laid on the table pending examination of the Treasurer's accounts by an auditing committee named from the floor, consisting of Philip S. Smith, Willis T. Lee, and Harry Fielding Reid.

ELECTION OF OFFICERS, REPRESENTATIVES, CORRESPONDENTS, AND FELLOWS

The Secretary then read the result of the ballot for officers of the Society for the year 1926, and representatives on the National Research Council, and of the ballot for Correspondents and Fellows. The following were declared elected:

President:

ANDREW C. LAWSON, Berkeley, California

First Vice-President:

HEINRICH RIES, Ithaca, New York

Second Vice-President:

LEWIS G. WESTGATE, Delaware, Ohio

Vice-President to represent the Paleontological Society:

STUART WELLER, Chicago, Illinois

Vice-President to represent the Mineralogical Society:

WALDEMAR T. SCHALLER, Washington, D. C.

Secretary:

CHARLES P. BERKEY, New York City

Treasurer:

EDWARD B. MATHEWS, Baltimore, Maryland

Editor:

JOSEPH STANLEY-BROWN, New York City

Councilors (1926-1928):

NELSON H. DARTON, Washington, D. C.
GEORGE H. ASHLEY, Harrisburg, Pennsylvania

Representatives on the National Research Council (July 1, 1926, to June 30, 1929):

K. C. HEALD, Pittsburgh, Pennsylvania
FRANK F. GROUT, Minneapolis, Minnesota

CORRESPONDENTS

JOHAN KIAER, Christiania, Norway. Professor of Paleontology and Stratigraphy and Director of Paleontology Museum.

WILLIAM JOHNSON SOLLAS, Oxford, England. Professor of Geology and Paleontology, University of Oxford.

JOHAN HERMAN LIE VOGT, Norway. Professor of Metallurgy, Christiania University, and Ordentlicher Professor of Geology and Mineralogy, Technical School, Trondhjem.

FELLOWS

ERNST VALDEMAR ANTEVS, Ph. D., Docent of Geology, University of Stockholm; Research Fellow, Shaler Memorial Investigation, Harvard University, Cambridge, Massachusetts.

FRITZ LOVE AUBIN, A. B., A. M., Chief Geologist, Marland Oil Company, Ponca City, Oklahoma.

ALBERT L. BEEKLY, A. B., Chief Geologist, Cosden and Company, Tulsa, Oklahoma.

CLIFTON S. COBETT, B. A., M. A., Ph. D., Chief Geologist, Standard Oil Company in the Dutch East Indies, Batavia, Java.

HAROLD E. CULVER, Ph. B., Ph. M., Ph. D., Geologist in charge of coal investigations, Illinois Geological Survey, Urbana, Illinois.

JUNIUS HENDERSON, B. A., Professor of Natural History and Curator of Museum, University of Colorado, Boulder, Colorado.

DANIEL FRANKLIN HIGGINS, B. S., M. S., Geologist, Loveland, Colorado.

WILLIAM CLIFFORD MORSE, B. A., M. A., Professor of Geology and Head of the Department, Mississippi Agricultural and Mechanical College, Mississippi.

FREDERICK BYRON PLUMMER, A. B., Geologist, Rycade Petroleum Corporation, Houston, Texas.

CARL ADOLPH SUSSMILCH, Principal, Newcastle Technical College, Newcastle, Australia.

GEORGE ALFRED THIEL, A. B., Ph. D., Instructor in Geology, University of Minnesota, Minneapolis, Minnesota.

FREDERIK TURVILLE THWAITES, B. A., M. A., Curator of Geological Museum, University of Wisconsin, Geologist in charge of well records, Wisconsin Geological Survey, Madison, Wisconsin.

FREEMAN WARD, B. A., Ph. D., Professor of Geology, University of South Dakota, State Geologist, Vermilion, South Dakota.

NECROLOGY

The Secretary announced the deaths during the year of nine Fellows of the Society and called for the customary brief oral tributes, as follows:

John M. Clarke, by Charles Schuchert.
David T. Day, by M. R. Campbell.
Richard R. Hice, by George H. Ashley.
William McInnes, by F. J. Alcock.
Willet G. Miller, by J. B. Tyrrell.
Frederick B. Peck, by Hervey W. Shimer.
Henry H. Robinson, by Isaiah Bowman.
Gilbert van Ingen, by W. D. Matthew.
Jay B. Woodworth, by Arthur Keith.

MEMORIALS

The following memorials are printed in the Proceedings of volume 37:

Memorial of Alfred Hulse Brooks, by Philip S. Smith.
Memorial of John Mason Clarke, by Charles Schuchert.
Memorial of Richard R. Hice, by George H. Ashley.
Memorial of William McInnes, by Frederick J. Alcock.
Memorial of Willet Green Miller, by Joseph B. Tyrrell.
Memorial of Frederick Burritt Peck, by Hervey W. Shimer.
Memorial of Robert Simpson Woodward, by Fred. E. Wright.
Memorial of Jay Backus Woodworth, by Arthur Keith.

Alfred H. Brooks.

MEMORIAL OF ALFRED HULSE BROOKS

BY PHILIP S. SMITH [1]

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INTRODUCTION

"Alaskan Scientist, Explorer, Historian." These few descriptive words, carved on an enduring granite shaft in one of Washington's most beautiful cemeteries, mark the last resting place of the body of Alfred Hulse Brooks. His useful life, which came suddenly to an end November 22, 1924, left a profound imprint on the science of geology, not only through his own direct personal contributions, but through his ability to develop other geologists and to administer and coordinate their work and interpret their results.

From his ancestry of old pioneer stock he inherited sound American principles, deep patriotism, and strong incentive to productive endeavor. His father, Major T. B. Brooks, an eminent mining engineer and

[1] Manuscript received by the Secretary of the Society, January 2, 1926.

geologist, whose work on certain iron-ore deposits of upper Michigan marked a prominent milestone in American geology, gave to his son a lasting trend toward love and appreciation of nature. To his father's influence also must be attributed the sound patriotism that led him to anticipate his country's need and answer her call when the great war loomed and broke. To the happy, congenial home of his boyhood with his father and his three sisters may be traced many of the qualities that endeared him most to his friends and associates.

Early Years

He spent his early years under diverse conditions, and the training he received followed no systematic plan. Born at Ann Arbor, Michigan, July 18, 1871, he went with his family to Germany when he was only six months old, and he remained there until he had reached the age of five years, when the family returned to America and made their home in Newburgh, New York. On his return to America the child was, of course, so completely a "foreigner" that he was more or less the butt of his companions; yet his life at Newburgh was very happy. A beautiful house and grounds, with animals and equipment that were a source of constant joy to the children, congenial friends and neighbors, a family circle in which adults and children participated on more or less equal footing—all helped to make the Newburgh period a series of red-letter days in his memory. In 1883 his mother died, and for several years a sister only a few years his senior became the mistress of the house—a fact that probably intensified the close mutual reliance of the members of the family on one another and made each a partaker in the family responsibilities rather than a mere onlooker. At Newburgh he received his elementary education in schools and from private tutors, but by far the most potent influence he felt in those days was that of his father, who fascinated his boy with tales of his own experience, encouraged in him a spirit of inquiry, and taught him how to find answers to his own questions from books and from his own observations.

Major Brooks, the father, had a strong desire to acquire land, wherever he happened to be and whatever might be the quality of the land. This trait brought him into close though informal association in business with Prof. Raphael Pumpelly, who had done geologic and prospecting work in northern Michigan on lands having possible value for their content of iron. The close friendship between the elder Brooks and Pumpelly, which began in 1866, also led the two to undertake about 1888 the development of the Roseland Plantation, a tract of about 5,500 acres, near Bainbridge, Georgia, under the name of the South Georgia

Live Stock and Planting Company. This plantation was the winter home of the Brooks and Pumpelly families for many years. Its operation gave a multitude of incentives to outdoor life, in which all members of both families participated, thus strengthening family ties. Rides through the pine woods about Roseland, the charm of the care-free life, the close companionship of friends—all left in his mind an ineffaceable memory of pleasure, duty, and happy growth.

First Work on Geological Survey

His first professional work of the kind to which he later devoted his life was begun in 1888, when he served as field assistant in a topographic party of the United States Geological Survey, in charge of H. L. Smyth, that was mapping certain areas in southern Vermont. Apparently Brooks was used in running traverses and in performing such similar jobs as usually fall to the lot of the younger, less experienced members of a survey party. In the next year (1889) he was out again with a topographic party of the Survey under Fred J. Knight, this time in the vicinity of Marquette, Michigan. Here he employed many of the methods he had learned from his father, and he must have felt special satisfaction in realizing that in this work he was retracing some of his father's footsteps. He does not appear, however, to have been keenly interested in the geology of the district. In fact, we know from his own lips that for a long time he was most strongly attracted toward a career as a topographer, and he was disposed to resent the fact that some of his assignments tended to divert him from topography to geology.

At the conclusion of his work in Michigan, late in the fall of 1889, he went with his family to Germany and remained there throughout 1890 and the early part of 1891. During this period he traveled some and he studied a good deal in the Polytechnik at Stuttgart and Munich. This trip to Germany, however, was not made directly for educational or similar purposes; it was determined upon because of the desire of his stepmother, his father having married again in 1886, to return to her native country. This life abroad undoubtedly stimulated the investigative spirit of the young student and broadened the foundation for much of his maturer work.

While the Brooks family was still abroad, Professor Pumpelly developed, with Major Brooks, a plan to have the United States Geological Survey, under the direction of Prof. C. R. Van Hise, investigate certain potential iron-ore lands in northern Michigan—a job for which some financial assistance had been obtained from the forerunner of the Chicago, Milwaukee and St. Paul Railroad, which owned large tracts of

land in that region. On the acceptance of this plan by the Geological Survey, young Brooks was invited to return to the United States and take part in the field-work with F. W. McNair, J. R. Finlay, Samuel Sanford, and others. He gladly accepted the opportunity, and in June, 1891, was at work on the job. It was hard work, but in it he learned many of the geologist's methods in a more or less frontier country, remote from settlements or even trails, where back-packing was the only practicable means of transporting supplies and equipment, and where in consequence only the bare necessities of existence and work could be taken along. All this was valuable experience on which to build his subsequent work in Alaska.

Student at Harvard

At the end of his field-work in Michigan, in December, 1891, he decided to go to Harvard, and after submitting a statement of his training and experience he was admitted to the scientific school of that university. Here he, like most other scientific students of that period, soon fell under the spell of Prof. N. S. Shaler, who marshaled great assemblages of natural objects and phenomena into organized hosts, enthralling in magnitude of conception and touching all phases of every-day life as it responded to conditions in nature. Under this magnetic personality and stimulating environment, Brooks delved more and more deeply into geology and became acquainted with many students of that science who continued in later years to be his associates. R. E. Dodge, M. A. Read, J. E. Spurr, and C. W. Purington are among those to whom he constantly refers in his letters of that period as participating in his studies and in his relaxations. Throughout his college course Brooks knew definitely what he wanted and went after it with unremitting enthusiasm. Unfortunately, his physique could not stand the strain of his unceasing work, and in March, 1893, he was compelled to consult a doctor, who found his condition so serious that he was ordered to stop work and was soon afterward sent to his home at Roseland, Georgia, to recuperate. Either the trouble was discovered opportunely, in its early stages, or the healthful conditions at Roseland and his good general physical resistance prevailed, for he built himself up rather rapidly and within a month or so was more or less actively at work around the plantation. When he had sufficiently regained his strength, he and A. F. Foerste began a geologic study of the Tertiary formations of parts of Georgia adjacent to Bainbridge and made a section along the Apalachicola River. Later in that same year he worked up some of his notes and

petrographic sections of the rocks of Orange County, New York, the county in which his home at Newburgh was situated.

In the fall of 1893 his health was so completely restored that he was able to return to Harvard and continue his studies. Apparently his academic status did not concern him deeply, though he was much gratified when he learned that, in spite of his having entered college a year after most of the other men and having lost nearly half a year on account of sickness, he would be given the degree of B. S. with the class of 1894. He had made good in all his college work and had several times been offered summer work with the Geological Survey.

Permanent Appointment on Survey

In June, 1894, Doctor C. W. Hayes offered him a position as his assistant in geological work in the Southern Appalachian region. The records show that Prof. W. M. Davis had recommended Brooks to Bailey Willis as one of the promising men who would be graduated from Harvard that year. Willis, however, had already arranged to make a graduate of another college his assistant. Apparently, therefore, on the strength of Professor Davis's recommendation and of his own general knowledge of Brooks's qualifications, Willis suggested him to Hayes. Hayes's offer was the beginning of a close friendship and personal association that lasted through life and left a deep impression on both men. Furthermore, this was the real beginning of Brooks's almost uninterrupted service of thirty years on the Geological Survey—a career in which he was extremely happy.

The enthusiasm of Brooks to take up the new work is well shown by the record that he reported to Doctor Hayes and went to work on July 22, 1894, although the formal papers requesting his appointment had not been approved and his appointment was not actually made until August 13.

His work in the Southern Appalachian region afforded him valuable additional experience, for it involved mapping relatively inaccessible country that presented complex geologic problems. In addition to the usual field traverses and observations, Brooks took special interest in the petrographic study of the material collected, and his first published paper was "Petrographic notes on some metamorphic rocks from eastern Alabama." His interest in petrography continued during his next field season and was maintained in the office work arising from it. In his report on the work in his charge, Doctor Hayes stated that this petrographic work of Brooks constituted the most complete study of the rocks of the Southern Appalachians that had been made. The skill he dis-

played in his work with Hayes, the ability to deal with complex geological problems, and his association with Prof. J. E. Wolff while in college led to his assignment for part of the field season of 1895 to geological work in New Jersey under Wolff. Most of his field-work during that season, however, was done in the Buckhannon region, West Virginia, as a member of a party in charge of J. A. Taff, with whom was also associated G. W. Stose.

On December 5, 1895, he and five other of the younger geologists of the Survey got together in his room and formed the A. A. A. (Association of Ambitious Assistants). The object of this organization was to furnish the members an opportunity to discuss freely their own work and that of others in a spirit of cooperation and without the formality that was required in the presentation of finished reports before the regular geological societies. In the early days of this organization the members met around in one another's rooms and discussed almost every live geologic question of the day. From this association sprang many close friendships and much valuable training, because each member was required to take part in the proceedings, to defend his own views, and to criticise the conclusions of others. The value of this association was at once apparent; so that soon the older Survey geologists applied for admission, and before long practically all the Survey geologists became members. Although, as time went on and the association grew to more than a hundred members, the old informal meetings and some of the old customs and traditions were given up, the club, which later changed its name to the Pick and Hammer Club, still exists and is a strong influence in maintaining the *esprit de corps* of the Survey.

In the early part of the season of 1896 Brooks was again in the field with Professor Wolff, working in the Franklin Furnace region, New Jersey, and in the later part he was in northern Georgia and southern Tennessee with Hayes. He spent the winter of 1896 and the spring and early summer of 1897 in working up his notes and preparing reports for publication. In all this work he showed indefatigable industry and marked skill in solving geological problems.

European Trip of 1897-98

In August, 1897, Brooks attended the Seventh International Geologic Congress at Saint Petersburg as one of the official delegates from the United States. In addition to attending the formal meetings, he took part in several excursions made during and after the Congress, visiting, among other places, the Urals, Donetz, Baku, the Crimea, Turkey, and Greece. This trip had a strongly marked effect on Brooks, as it made

him acquainted with many prominent Old World geologists and with problems that have become classic. On this trip also he became better acquainted with some of his American colleagues and gained a lasting appreciation of the work of such men as A. C. Lawson and R. A. Daly. The interest then awakened in him in some of the problems of Russia and Siberia was revived when his Alaskan studies led him to turn to the consideration of these countries because of their proximity to Alaska.

At the close of the Geologic Congress, in September, 1897, Brooks decided not to return to the United States, but, after further travel, to go to Paris and study at the Sorbonne. Here he studied principally petrography and geology, working in La Croix's laboratory and attending lectures by Fouqué, Bertrand, and De Launay.

Beginning of Alaskan Career

He had spent only a few months in his studies in Paris when he received a cable from the Geological Survey, offering him a chance to return and serve as a member of one of the parties that would be sent to Alaska in the spring of 1898. This was an opportunity that he had long wanted. His close association with Doctor Hayes, who had made a notable exploratory trip to Alaska in 1891, had long before fired him with an interest in that Territory, and he had several times applied for assignment to work in Alaska if the Survey ever had the opportunity to undertake investigations there. Furthermore, he welcomed the chance to utilize his geologic knowledge in directing the intelligent development of a new region on sound scientific principles. It was, therefore, with great joy that he accepted this assignment and within a day had closed his academic work and was on his way back to Washington. For the next few weeks there was a lively scurry to make the necessary preparations, because he reached Washington only in March and the expedition left Seattle April 5, 1898.

This was the beginning of Brooks's Alaskan career—a career to which he unceasingly devoted his best efforts for a quarter of a century, and in which he established a reputation not only in his chosen profession, but as an empire-builder, that made him more revered and better known than any other man connected with the development of this great Territory.

The party to which Brooks was attached as geologist was in charge of W. J. Peters, and its plan was to survey the lower part of White River and as much of Tanana River as time would permit. This trip contemplated the survey of an area that had been seen only in part by white men, and even for the part seen there were not maps sufficiently definite

to be of material assistance in a new exploration. The party ascended White River—a turbulent glacier-fed stream, which, according to all available information, including that of the natives, could not be ascended in boats—and its tributary, Snag River, for a distance of about 150 miles, a portage of 5 miles, and a journey down the Tanana of more than 600 miles. The party achieved all the main objects of the trip, studied all phases of the physiography and geology of the region, and suggested many interpretations that have stood the test of later, more detailed investigation. Brooks's own realization of the incompleteness of some of the records covering this area are well stated in his report on this trip, for he says: "Only those who are familiar from personal experience with the present conditions of exploring such a region can understand why scientific observation must be more or less fragmentary. The explorer must, of necessity, spend a large part of his energies and time in overcoming the physical obstacles to his progress, and geologic investigation, except of the most hasty kind, can be made only at such times as conditions of traveling permit. These facts the reader should bear in mind when he feels like criticising the author for leaving so many important questions unsettled." This warning might well be repeated to any one who fails to rank Brooks's work among the outstanding examples of a contribution to the geology of a frontier region.

Pyramid Harbor–Eagle Trip

The next year (1899) Brooks made another reconnaissance trip, this time from Pyramid Harbor (a boom town, now deserted, southwest of Skagway), by way of Klehini River and the headwaters of the Alsek, to Lake Kluane, across the upper White River basin to the basin of the Tanana; thence down the Nebesna to a point where the party crossed the Tanana, and thence along the divide north of the Tanana to Forty-mile River and Eagle, on the Yukon. In addition to Brooks, this party consisted of W. J. Peters, topographer in charge, and four assistants and camp hands. The equipment and supplies were carried by a pack train of 15 horses. Some measure of the mere physical stress of the trip may be gained from the facts that the party moved camp more than 600 miles in 66 days; that in going that distance they had to chop 40 miles of trail—an exercise in which all of its members participated; that 8 of their 15 horses became exhausted and had to be shot before completing the trip; that they had to build their own boat to get across the Tanana, and that their route compelled them to cross many glacial streams, in trips so hazardous that their success seemed almost impossible. In spite of these physical difficulties Brooks obtained a wealth of

data regarding the region and especially regarding its mineral deposits. His report on the district states that his aim was to give such facts and conclusions as would be of practical value rather than to attempt a technical treatment of the large amount of material collected. To this aim he adhered closely, and his conclusions, especially those relating to the mineral deposits, are clear-cut and definite, even though at the same time he set forth many uncertainties. Although supplemented and modified in detail by the more complete data gained by later work, the fundamental conclusions he reached have proved well founded and remarkably accurate.

First Survey of Nome Region

After completing the long field trip from Pyramid Harbor to Eagle, the party started to go home by way of the Yukon to Saint Michael, where they expected to take an ocean steamer to Seattle. On arriving at Saint Michael, however, they met a Geological Survey party consisting of T. G. Gerdine and D. C. Witherspoon, topographers, and F. C. Schrader, geologist, who had recently completed surveys in the Koyukuk-Chandalar regions. They also encountered a rush of gold-seekers bound for Nome, a hundred miles distant across Norton Sound. The desirability of obtaining information regarding this new gold camp decided Brooks, Schrader, and Witherspoon to make a hurried examination of Nome. It was then October and work had been stopped on nearly all the placer diggings because the creeks were frozen. Most of the equipment of the Survey party had been worn out on the trips already made and had been discarded, so that the new work was done mainly from Nome as a base, by back packing sleeping bags, provisions, and instruments into the adjacent mountains and gulches on circuits of several days each. In spite of these difficulties, the main geologic features of the country were correctly determined, and a topographic sketch map was prepared by Witherspoon, showing the region within a radius of ten miles of Nome.

The unsanitary conditions at some of the camps caused Brooks to become infected with typhoid fever. On reaching Seattle he was miserable, and he became so much worse that on his arrival in Washington he was in a dangerous condition and was put to bed, where for weeks he was critically ill. His good physical condition and the unremitting care of his friend and associate, T. W. Vaughan, finally pulled him through and he went ahead preparing his reports. In spite of his illness, a report that made 50 printed pages, covering the work around Nome, with maps and illustrations, was completed and transmitted to the Secretary of the

Interior by the Director of the Survey on February 1, 1900, less than three months after the party returned to the States. Even at that, the Director felt called on to apologize for the delay in sending the report and mentioned Brooks's illness as the explanation.

This preliminary report on the Nome region was characteristically full of valuable yet guarded interpretations, which, however, were not so hedged about by qualifications that they were meaningless. Rather they were sufficiently marked by warning signals that commanded attention, and then the author's interpretations were thoroughly and definitely given. The report thus resembled a well-made harbor chart that first called attention to the dangers of the coast and the entrance and then outlined the safest route through the obstructions.

Typical warnings and advice from this report are:

"In the coming spring (1900) it is expected that there will be a very large influx of population into Nome and adjacent regions. . . . It is evident, therefore, that the region, compared with other parts of Alaska, will be densely populated, and it is not likely that the high rate of wages paid last year will be maintained. . . . It must be remembered, however, that the beach placers, like all others, are not inexhaustible, and that they do not by any means extend along the whole coast. . . . It would be very wise for all inexperienced newcomers to save money for their return passage. . . . There will be good opportunities at Nome for experienced miners. . . . We believe that the Nome region has a great future."

Survey of the Nome Region

After completing the preliminary report on the Nome region Brooks turned at once to the preparation of the report on his Pyramid Harbor-Eagle trip and completed it before leaving for the next field expedition, in June. The widespread interest in the Nome region and the great influx of prospectors led the Geological Survey to send into the Nome region and the western part of Seward Peninsula a geologic party in charge of Brooks, with G. B. Richardson and A. J. Collier as assistants and five camp hands, and a topographic party in charge of E. C. Barnard, while another party, in charge of W. J. Peters, topographer, and W. C. Mendenhall, geologist, with four assistants and camp hands, went into the eastern part of the peninsula. The party in charge of Brooks brought back geologic information regarding a tract of more than 6,000 square miles, and although he disclaimed the idea that the report on the work done was more than a hasty summary of a preliminary reconnaissance of the gold field, the conclusions expressed were remarkably broad and sound. Characteristically, in writing this report, Brooks stressed the need of making it of immediate and practical value to the miner and

prospector and the intelligent reader not specially versed in geology, rather than indulging in abstruse or speculative theories of interest principally to specialists in geology. As a result, the report was of wide use and became a notable force in directing intelligent prospecting and development. Unfortunately, some of the suggestions and predictions made were not followed for several years. For instance, in 1900 the probability that ancient gold-bearing sea beaches would be found was predicted in the following terms:

> "As these coastal plain deposits were laid down on the margin of the ocean, we should expect old sea beaches to be found in these gravels. If such beaches are found, they are likely to prove as rich as the present beach at Nome. It would, therefore, be well for prospectors to examine carefully the seaward escarpments which mark the limits of the terraces. These bluffs are quite likely to mark an old sea beach. In such types of deposits we should expect their extension to be more or less parallel to the present coastline."

In spite of this definite suggestion, made in 1900 and published in 1901, it was the winter of 1904-05 before the rich ancient buried beaches were actually discovered and their exploitation begun.

Southeastern Alaska Work

By the time the office work of the report on the Nome region was completed another field season had come around, and late in June, 1901, Brooks started for southeastern Alaska to investigate mining developments in that region. In this project he was associated, both in the field and in the office, with C. C. Brayton. Most of the field studies were carried on in the Ketchikan district, where in the course of two months the party traveled about 1,200 miles, mostly in a small gasoline launch, visited more than 150 claims and mines, and made reconnaissances of about 2,000 square miles. In order to realize the difficulties under which the work was done, it should be remembered that it rained more or less on 45 of the 60 days spent in the region. At the conclusion of the work in the Ketchikan region, late in September and early in October, the party worked on the general geologic features and relations of the region to the north and visited the mining developments near Juneau.

Southeastern Alaska is an intensely difficult region for geologic work. It embraces sedimentary rocks ranging in age from early Paleozoic to Tertiary, igneous rocks of various composition and modes of formation, complex structure produced during different periods by mountain-building forces and profound intrusive activity, and economic products of greater variety than are found in any other Alaskan mining district. The intricate problems connected with these different phases of geology

are still not completely solved, but the start toward their solution then made by Brooks has been of inestimable service to later workers in this field and has long been a valuable guide to the prospector and miner. The results of this field-work were rapidly put in shape for publication and within a year the report was published and in use.

Trip to Mount McKinley Region

In 1902 Brooks again went to Alaska, this time in charge of a party whose task was to obtain all possible information regarding the geology, topography, geography, and mineral resources of the vast unexplored tract along the western and northern slopes of the Alaska Range. In this work he was assisted by L. M. Prindle, assistant geologist; D. L. Reaburn, topographer, and four camp hands. The party traveled with a pack train of 20 horses, only 11 of which survived to arrive at Rampart, where the expedition closed its field-work. In 105 days the party moved about 800 miles and obtained geologic information regarding an area of at least 10,000 square miles. This may reasonably be regarded as Brooks's greatest piece of exploratory work. The party left Seattle May 15, 1902, and put ashore at Tyonek, on the western shore of Cook Inlet, on May 27. From Tyonek they worked northward to Beluga River; thence along the slopes of Mount Susitna to Skwentna River, a swollen, rushing torrent that swept horses and men off their feet whenever they attempted to cross. Finally, swimming the Skwentna, they went through a region of heavy timber and brush, where continuous trail chopping was necessary; then up the Kichatna until they discovered a pass that they called Rainy Pass, which led into a valley tributary to the Kuskokwim, and thence northeastward along the front of the mountains. This last part of the route was far better for travel, except for the crossing of the roaring, glacier-fed streams, which was always exciting, though not pleasant, as occasionally a horse would be swept off its feet and rolled over; but, fortunately, none were lost.

When near Mount McKinley, Brooks made a side trip to the ridges within nine miles of the summit of this stupendous mountain, which had never before been approached by white men. While he realized that the plan of the exploration on which he was engaged precluded any attempt to scale the mountain, he could not but feel regret that there was neither time nor means for reaching a higher altitude. Still eastward the party pushed its way across the Nenana, the last of the large streams flowing northward from the mountains, and later met a white man and some natives, the first human beings they had seen in nearly three months. On September 1 they crossed Tanana River, headed for Ram-

part, on the Yukon, which they reached on September 15, in spite of the assurance of the Indians whom they met on the Tanana that it was impossible to take horses through to the Yukon. In his account of this trip Brooks writes: "To the natives [on the Tanana] the arrival of white men from the mountains seemed little short of miraculous." When we consider the lack of information then available about this country and the difficulties of travel, we can only indorse the Indians' conclusion that the advent of this little band of hardy white explorers was indeed "miraculous."

February 23, 1903, marked a most important date in Brooks's life, for on that day he married Mabel Baker, of Washington. This marriage was the beginning of an ideal home life—one that was unusually happy and congenial. Mrs. Brooks is a highly cultured woman of keen intellect, who shared actively her husband's personal and scientific interests and at all times had a sympathetic understanding of the man and the scientist. She collaborated with him in putting many of his manuscripts into final form, and in fact will complete some of his unfinished work. At their home their friends could always count on finding genial hospitality, friendly comradeship, and stimulating association. Later, two children were born, Mary (1905) and Benton (1909), in whom Brooks renewed many of the joyous memories of his own very happy childhood.

Placed in Charge of Survey's Alaska Work

The early investigations of Alaska had been administered mainly by a committee of Survey geologists and topographers. This form of administration proved cumbersome and failed to place direct responsibility for coordinated planning and execution. Finally, in 1902, the Director placed the supervision of the geologic work in Alaska under Brooks, and that of the topographic work under R. U. Goode. In spite of the harmonious cooperation of Brooks and Goode, this plan did not work out so well as might have been desired, because in Alaska the two kinds of work are necessarily tied so closely together in actual operation that usually a party consists of both geologists and topographers, and the proper coordination of their work requires one directing head. As a consequence, on the death of Mr. Goode, in June, 1903, Doctor Hayes recommended to the Director that a new unit be established to handle all Alaskan affairs for the Survey; that this unit be placed in the Geologic Branch and made coordinate with the existing divisions of geology, chemistry and physics, and mineral resources, and that Brooks be placed in charge of it. This plan was approved both by the Director and by

the Secretary of the Interior, and early in July, 1903, the new unit began its work and Brooks began his career as the recognized administrative officer in charge of one of the Survey's major activities, though for a long time before this he had taken a large part in the councils of the office and in the preparation of its plans.

Although throughout most of the following 20 years his principal duties in the Survey were administrative, he never ceased gathering at first hand information relating to Alaska. It is true that after 1903 he made no long full-season trips, such as he had made from 1898 to 1902, yet he spent several months of every year in the field visiting all the parties wherever possible and making independent trips to mining camps and other areas concerning which supplementary information was desired. In all, he made 24 trips to Alaska. As a consequence, he never ceased to be a fieldman, and his point of view in all his administrative work was never that of a desk autocrat, but always that of an investigator working sympathetically with his men, who were constantly confronted with unusual conditions. His greatest strength in administrative work was his willingness to place responsibility on his assistants, holding them accountable for their results, but not attempting to interfere with the details of their plans and methods.

Although there were some heart burnings when Brooks was placed in charge of the Alaskan work, the splendid spirit in which he conducted his organization built up such a spirit of loyalty, regard, and admiration among his assistants that the Alaskan unit became conspicuous for its *esprit de corps*, even in an organization like the Survey, which has long been remarkable for that spirit.

Geology and Geography of Alaska and Other Publications

Brooks not only did not abandon his field work, but he actually increased his productive investigation and study during his period of administrative responsibility. This fact is shown not only by publications based on his own observations, but by publications in which he interpreted or correlated the work of others. One of the most noteworthy examples of his excellence in summarizing the work of others as well as interpolating his own views was the report entitled "The Geography and Geology of Alaska," published by the Geological Survey as a professional paper. This volume was started as a short magazine article, but as data were accumulated it gradually outgrew these provisional bounds, so that when first submitted for publication by the Survey in 1903 it was equivalent to 200 printed pages. The results of new explorations, however, kept pouring in, and in order to make the volume complete

additional subjects required treatment. The manuscript was therefore withdrawn for supplementary data and was not resubmitted until late in 1904. It was finally printed and distributed in 1906. The vast amount of information first brought together in a book of more than 300 pages at once stamped the author as the authority on Alaska and gave him an international reputation. Although this volume was necessarily in large part compiled from the work of others, Brooks's own familiarity with a considerable part of the territory justified him in reaching and expressing many personal conclusions, some of which were even at variance with those expressed in the reports from which his information was taken. So thoroughly was his work done that even today, twenty years after its publication, there is no more complete and accurate book on the general geology and geography of this territory, although, of course, many of its details could be amplified or modified in the light of the more complete data now available.

Every year from 1904 to 1916 and from 1919 to 1923 he prepared a statement on the whole Alaskan mineral industry. This statement took the form of an estimate, issued immediately at the end of the year, and a more complete analysis prepared after the data from most of the producers had been collected and digested. He was also alert to anticipate the public need for data on special topics, working these up in the midst of his numerous other duties. Good examples are his timely reports on Alaska coal—its distribution, its possible markets, and its utilization—a topic which he early sensed had great importance in the development of the Territory and the problems relating to it. The first of his reports on this subject was printed in 1905, and subsequent contributions were made public in 1910, 1911, and 1913.

Other subjects that he considered in a broad way were the "Geologic features of Alaskan metalliferous lodes," published in 1911; "The future of gold placer mining in Alaska," published in 1915; "Antimony deposits of Alaska," published in 1916; and "The future of Alaska mining," published in 1920. It was not only in the reports bearing his name, however, that those who were intimately associated with Brooks recognized his authorship. Among the many reports turned in to him for publication some were so incomplete and otherwise unsatisfactory that they could not be utilized in the form in which they were submitted by their authors. Many of these papers were worked over by Brooks during his scanty spare time; suggestions and constructive criticisms were made, and if the author was not available, or if Brooks felt that the author could not satisfactorily remedy the defects, he himself did the

work, even though it might require weeks of writing the text or of drawing the necessary illustrations.

To resume the more or less chronological story of Brooks's life: In the field season of 1911 he was attached to the party of the Secretary of the Interior, Walter L. Fisher, during its visit to Alaska. Brooks's wealth of information regarding the Territory was a source of much assistance to the Secretary in helping him to get a broad view in the short time at his disposal. This association was the beginning of a personal friendship and a mutual appreciation that undoubtedly contributed to the selection of Brooks as a member of the Alaska Railroad Commission when it was established in 1912.

While Brooks was with the Secretary on this trip, Doctor Hayes, the Chief Geologist of the Survey, resigned to accept employment in one of the large oil companies operating in Mexico. After thorough consideration of all the geologists who might effectively fill the position thus vacated by Doctor Hayes, the Director offered it to Brooks. Brooks, however, though deeply appreciative of the recognition that actuated the offer, requested that he be allowed to continue his Alaskan work. The public notice sent out by the Survey regarding this matter contains the following statement:

"While regretting Mr. Brooks's choice, both Secretary Fisher and Director George Otis Smith, of the Survey, have approved the same, and Mr. Brooks will continue in charge of the Alaskan geologic work. Mr. Brooks states that he has reached the decision after careful consideration of the matter, and while he fully recognizes the honor conferred by the offer of the higher office, he believes that his field of greatest usefulness lies in the continuation of administration of the Geological Survey work in Alaska, work which he believes has in reality hardly begun."

Applied Geology

Brooks took occasion, on his retirement from the presidency of the Geological Society of Washington, in December, 1911, to deliver a notable address on "Applied geology," as he styled the trend of geology toward the solution of practical problems. In this address he discussed subjects that had always been very close to his heart, and his championship of them in this paper was only the written expression of the championship that he, following his father's example, had displayed throughout his own scientific work and throughout his direction of the work of others. The concluding paragraph of this address may well be quoted as summing up what may be regarded as his fundamental geologic creed, and it emphatically proves his estimation of pure science:

"As I see it, there lies no danger in the present trend toward applied geology, provided our applied geology rests on a broad basis of scientific research. If the spring of pure science is cut off, the stream of applied geology must soon run dry. There is no field of pure geology which will not yield results applicable to questions of material welfare. On the other hand, any given investigation in applied geology may lead to problems of paleontology, petrography, geophysics, or other branches of pure science. In view of the pressing demand for results, we are justified in giving precedence to those fields of investigation which promise the earliest returns of material value. There is, however, grave danger that, carried away by the present furor for practical results, we may lose sight of our scientific ideals. Applied geology can only maintain its present high position of usefulness by continuing the researches which advance the knowledge of basic principles. Future progress in applied geology depends on progress in pure geology."

Alaska Railroad Commission

The controversies regarding the acquisition of certain mineral claims in Alaska and the general interest that had been stirred up by the supporters and antagonists of "conservation," whatever that much-abused term means, had brought Alaska more clearly into public sight and had indicated that something should be done by the Government for the development of the Territory. Among the various suggestions made, some of which had been carried far enough to be outlined in bills presented to Congress, was one to study the location of possible railroad routes in the Territory. Already, in 1906, Brooks, with his usual perspicacity in discerning key problems, had discussed the possible railroad routes. This clearness of vision, as well as his acknowledged unique and comprehensive knowledge of Alaska and its resources that were pertinent to any railroad enterprise, caused him to be selected as one of the commissioners when, on August 24, 1912, Congress passed an act creating a commission of four to "conduct an examination into the transportation question in the Territory of Alaska . . . to make report of the facts to Congress, . . . with their conclusions and recommendations in respect to the best and most available routes for railroads in Alaska, which will develop the country and the resources thereof for the people of the United States." . . .

The Alaska Railroad Commission, consisting of Major J. J. Morrow, Corps of Engineers, U. S. Army, chairman; Alfred H. Brooks, vice-chairman; L. M. Cox, civil engineer, U. S. Navy; and C. M. Ingersoll, consulting engineer, of New York City, convened as soon as possible, after their appointment, at Seattle and sailed for Alaska September 10. They examined personally as many of the routes as the season and other conditions would permit, and returned to Seattle by November 17. The

Commission returned to Washington by way of Ottawa, studying several Canadian railroads, so as to obtain additional pertinent data. All the information obtained was compiled and incorporated in a report, prepared in Washington between December 2, 1912, and February 6, 1913, which was transmitted by President Taft to Congress with his favorable indorsement of the recommendations made.

The Commission recommended the construction of a railroad from Chitina, on the Copper River, to Fairbanks, though it also indicated the desirability of another line that should make available the mineral resources of the lower Susitna and Matanuska valleys and afford possible extension into the Kuskokwim region.

The report was, of course, the expression of the views of the Commission as a body, but it is obvious that the ability of the Commission to amass such a comprehensive array of data in the short time available must have been due to their guidance by Brooks's familiarity with sources of information and with the means of accomplishing desired aims expeditiously. The railroad that was ultimately built by the Government does not follow the principal route proposed by the Commission; it follows the route from Seward to Fairbanks that was discussed by the Commission. This change in the route was regarded by Brooks as a mistake. It was not, in his judgment, in accord with the facts nor with the best mode of developing the Territory.

Daly and Malte-Brun Medals

Recognition of the high value of the scientific contributions made by Brooks was brought to a focus by his service on this Railroad Commission and by the appearance in 1911 of his monograph on the Mount McKinley Region, a report that was started to describe his trip in 1902, but that was later amplified to embrace a larger area and to include the results of the work of a great number of explorers and others. This recognition was in part expressed in April, 1913, when the American Geographical Society presented him its Charles P. Daly gold medal "in recognition of the excellence and importance of his work in exploration and mapping Alaska." Brooks deeply appreciated this honor, but, with his customary modesty, he wrote in his letter of acceptance:

> **"I must therefore regard this award as made not so much for personal merit, but rather as a recognition of the value of the geological work of my colleagues and myself in exploring Alaska. . . . I am sure that this will inspire us to continue our efforts to increase the geologic knowledge of Alaska."**

In May, 1913, the Société de Geographie of Paris unanimously awarded the Conrad Malte-Brun gold medal to Brooks, expressing "its appreciation of and admiration for the great scientific service rendered by our laureate," and characterizing his work in the Alaskan service as follows: "He has directed it ever since with a zeal equaled only by his ability, and has given to his numerous collaborators an example of untiring energy."

Another honor that came to Brooks in 1913 was his designation as one of the delegates to the Twelfth International Geologic Congress. After having spent part of the field season of 1913 in Alaska, he returned to attend the meetings of the Congress at Toronto in August, and then joined the excursions through the Canadian Cordillera, visiting many of the mining camps in British Columbia.

Preparation for Military Service

The outbreak of the European War in 1914 turned the attention of every one to that catastrophe. Brooks, with his customary clearness of vision and his resourcefulness in drawing conclusions from his observations, early became imbued with the idea that this country should realize its need for preparedness. The recognition of a problem was to him the incentive for constructive suggestions for its solution. In this case his suggestion took the form of a memorandum to the Director that was transmitted to the War Department in May, 1915. It suggested the establishment of a roster in the War Department of the engineers and others in the Government service whose special qualifications might be of value to the military establishment in time of war, especially if these engineers could be given some preliminary training in military methods. The obvious merits of this suggestion and its practicability must have appealed at once to those in the War Department into whose hands the memorandum came, for in acknowledging its receipt, in a letter dated June 5, 1915, General Macomb stated that the plan had been carefully studied, and that they saw great possibilities in it. In fact, he stated that he believed "the idea is going to have a much wider application than Mr. Brooks indicated." In looking back at the National Defense Act of June 3, 1916, we may well believe that the creation of the Reserve Corps for all kinds of line duty, and also for various staffs and departments, may possibly have been what General Macomb meant by "wider application."

Preparedness, however, was not only a thing for others. To Brooks it meant personal action, so when a citizens' training camp was estab-

lished at Fort Oglethorpe, Georgia, he applied for admission to it and was accepted. He was also probably instrumental in getting other geologists in the Survey—Sidney Paige, H. G. Ferguson, and J. F. Hunter—to join this training camp. While this training camp lasted, during May, 1916, he threw himself with whole-souled interest into the task of learning the new duties of a private soldier. His letters relating to his new experiences bubble over with enthusiasm. They contain such expressions as: "Tell everybody not to miss it [the training camp] on any account. . . . It is great to have some one else have all the responsibility. In fact, this has been one of the finest things I ever did."

After his experience at training camp and his usual trip to Alaska during the field season, Brooks came back with an even deeper sense of his responsibility to his country as its relation to Europe became increasingly more involved, and on December 5, 1916, the Director of the Survey transmitted to the Chief of Engineers, with his approval, Brooks's application for a commission in the Engineer Officers' Reserve Corps. Many delays in acting favorably on this application ensued, but on April 23, 1917, a commission was issued to him as Captain in the Engineer Officers' Reserve Corps. Brooks reported to the training camp near Washington on May 17 and his service in the Survey was discontinued soon afterward. Until late in July his whole time was devoted to training at the camps near Washington. Finally, he was commissioned as major and later orders came for him to go abroad. On August 15 he embarked from New York on the *Andania* and reported to the Chief Engineer of the American Expeditionary Force in France early in September.

Chief Geologist, American Expeditionary Force

The fact that geologists might be of service to the American forces in France seems to have been realized first by General S. A. Cheney and Colonel Ernest Graves, who needed geologic advice in handling problems relating principally to water supply and military mining. On their recommendation that geologists should be attached to the headquarters staff, the Chief of Engineers selected Brooks and permitted him to name his assistant. Brooks chose Captain Edwin C. Eckel, an engineer of long experience, who had been with him at training camp and with whom he had formerly been associated in the Survey. Apparently the possible military service of geologists was not well understood or appreciated in the Army, for after a month or so Captain Eckel was assigned to other duties, and only after an earnest appeal by Colonel G. A. Youngberg, the head of the Division of Front Line Engineering, was the geo-

logic section continued. The personnel attached to the geologic section under Brooks as chief geologist underwent many changes from time to time. Captain (later Major) M. F. La Croix was soon assigned to Eckel's place. In April, 1918, Lieut. T. M. Smithers was assigned to the section for temporary duty, and in July a plan for adding several geologists to the force was approved. Under this plan Lieut. R. S. Knappen, Lieut. H. F. Crooks, Lieut. Wallace Lee, and Lieut. Kirk Bryan, who were already in the service in positions that did not utilize their geologic knowledge, were added to the section and ordered to report as soon as they could be spared from their other duties. Request was also made on Washington for eight additional geologic officers, but the signing of the Armistice interrupted this plan, and only one of these officers arrived in France.

The geologic section of the American Expeditionary Force was charged with the duty of collecting and presenting information relating to the physical conditions of the terrain as they affected the construction of field-works, the source and quantity of water, the distribution and occurrence of road metal, and such other subjects as were related to the application of geology to military matters. Most of the data had to be compiled from existing publications, as there was little time or opportunity to collect original information. In all, some forty-eight formal reports and thirty-one maps were prepared by the geologic section, besides numerous memoranda and much informal advice. In terms of area the eight geologic engineering maps relating to field fortifications covered more than 7,800 square kilometers, and those relating to water supplies covered nearly 15,000 square kilometers. These figures show what a surprisingly large amount of work was done by the geologic section, for it should be remembered that during all the time the section was in existence, except the two months just preceding the Armistice, the personnel on the average included only two geologists and one clerk.

Although we may suppose that for some time the headquarters staff hardly knew what kind of a *lusus naturæ* a geologist was, Brooks, through his personality, his quick comprehension of problems, and the practicality of the reports he prepared, demonstrated the usefulness of geology to military operations. He was promoted October 3, 1918, to the rank of Lieutenant Colonel, and when he left the service General Pershing in a personal letter to him said: "Your work was of a constructive character in a field new to military service, and the results of your efforts were becoming manifest to all."

After the Armistice, Brooks spent some time in closing up the work he had in hand and attending to all the details required in terminating

his service in the Army. On February 6, 1919, he was directed to proceed to Paris for duty with the American Commission to Negotiate Peace, an assignment that lasted until April 19. Brooks's principal duty with the Commission appears to have been the preparation of an analysis of the iron, steel, and associated industries of Lorraine, the Sarre District, Luxemburg, and Belgium. In this task he was assisted by Lieut. H. F. Crooks, who compiled the data on which many of the statistical tables are based, and Major La Croix, who was especially conversant with conditions in Belgium and parts of Luxemburg. As already noted, both of these officers had at one time been attached to the geologic section of the A. E. F. The value of the service rendered the Commission was specifically recognized by General Pershing in a personal letter to Brooks, in which he said: "You have been specially commended by members of the Peace Commission for the excellence of your work in investigating and reporting upon the iron, steel, and related industries of Central Europe."

Soon after completing his work with the Peace Commission, Brooks received orders to return to the United States. He arrived on April 28, 1919, and on May 3 was honorably discharged from the service and was at once reinstated in his old post in the Geological Survey. The net results of his military service may be summarized as follows: He reached the rank of Lieutenant Colonel, won the right to wear three gold war service chevrons, and for the first time "sold" geology to the military establishment through the sheer force of having delivered useful service.

Resumption of Duties in the Geological Survey

Back in the Survey, he at once picked up the broken threads of his Alaskan work and threw himself into the double task of arranging for the coming field season and of writing up some of the accumulated results of his application of geology to military uses. In August he accompanied John Hallowell, assistant to the Secretary of the Interior, to Alaska to study some of the many general problems relating to the development of the Territory, as well as to get information regarding the progress made in his own special fields of study. This trip was marked everywhere by ovations to Brooks. His return after two years' absence was greeted by all Alaskans as the home-coming of a much-loved and honored son.

In the spring of 1920 the certainty that Alaskan matters required more thoughtful consideration than had ever been given to them led John Barton Payne, Secretary of the Interior, to appoint a committee of representatives of the Interior, Post Office, and Agricultural Depart-

ments to advise him "as to what immediate steps can be taken to better conditions in Alaska—what industries can be developed and resources exploited to give employment to a resident population which, in turn, will give a home market for Alaskan products." Brooks was the representative of the Interior Department on this committee and its chairman. The committee brought in a report full of terse, practical suggestions and recommendations, many of which have been adopted.

With the completion of the Alaskan Committee's report, Brooks made a flying trip to Colgate University, New York, where he received the honorary degree of D. Sc. in recognition of his lifetime service to science, and especially of his contributions to the knowledge of geology and geography of Alaska. In July, 1920, the Secretaries of the Interior and the Navy visited Alaska, and Brooks accompanied them on part of their trip, and then made hurried examinations of the condition of the mineral industry in some of the adjoining regions, returning to Washington in October.

In the midst of his regular duties, Brooks found time to take an active part in the proceedings of many of the scientific societies in Washington, and in 1921 was honored by election to the presidency of the Washington Academy of Science. His address on "The scientist in the Federal service," delivered on his retirement from that office, was a luminous statement of the vagaries of the Government service, a clear exposition of the limitations and opportunities of that work, but above all was a graphic picture of that army of men who express their recognition of public duty and self-sacrifice by action rather than words. The lessons taught by this keen, analytical dissection of the scientist in the Government service is equally applicable to research work in general, and the pitiless exposure of sham and the sympathetic understanding of real investigative work apply alike to the labors of many scientists, both within and without the service.

One of the recognitions of Brooks's service and of the organization he had built up was the definite establishment on April 1, 1922, of the Alaskan unit of the Survey as an independent branch, coordinate in rank with the other field branches. In the official announcement of this action, the Director wrote:

"This change is hardly more than a change in name, as the Alaskan work has long been only nominally under the administration of the Geologic Branch. . . . It has long been apparent that, in both theory and fact, the Division of Alaskan Mineral Resources is the Geological Survey of Alaska, but no less evident is the economy effected and the efficiency attained by continuing it as an integral part of the much larger organization carrying on

similar work throughout the United States. . . . Mr. Brooks's official title as chief of the branch will be Chief Alaskan Geologist, which he has been in fact so long."

Trip to Alaska and Japan with Department of Commerce Party

The Department of Commerce, which is charged, among other things, with duties relating to many Alaskan industries and trade in general, decided to study several of the problems relating to an area in the North Pacific. Accordingly, C. A. Houston, the Assistant Secretary of that Department, with several specialists from both his own and other Government departments, planned to visit in 1922 some thirty points in Alaska and the adjacent islands, and then to go to Japan. This trip offered so unusual an opportunity to have Brooks visit many out-of-the-way places in Alaska that the Director of the Survey desired to have him attached to this party. On the other hand, the great benefit that would be gained by having a man so conversant with Alaska as Brooks available to discuss matters with Secretary Houston made Brooks's addition to the party highly acceptable to the Department of Commerce. The party left Seattle in June, 1922, on the coast guard cutter *Mojave* and visited much of the coastal portion of southern and western Alaska and adjacent islands, as well as parts of the coast of Siberia and Japan. While in Japan, Brooks suffered a slight stroke, which somewhat paralyzed his leg and side and necessitated his leaving the party and returning at once to Washington. When he reached Washington, although he was under a doctor's care, he had recovered sufficiently to attend to his official duties in the Survey. In fact, his realization of his condition and of what he wanted to accomplish made him force himself to work when, for his health's sake, he should have rested at home. He was a true soldier, however, and his sense of obligation to the office, to Alaska, and to science did not permit any relaxation or faltering in giving at all times his full measure of service.

Trip to Australia with Second Pan-Pacific Scientific Congress

The Pan-Pacific Scientific Congress, which had been formed to discuss problems relating to countries contiguous to the Pacific, was to hold its second meeting in Australia in 1923. Many of the problems to be discussed necessarily related to matters concerning which Alaska could either contribute data or might benefit by the reports from other countries. Brooks was therefore named as one of the delegates to this convention from the United States. The other geologists in this delegation were N. M. Fenneman, H. E. Gregory, and T. W. Vaughan. In addi-

tion to attending the formal meetings, the delegates traveled extensively through Australia and adjacent regions. Brooks prepared and read several papers at the Congress and took part in excursions to Melbourne, Sydney, Adelaide, and Tasmania, visiting many of the mining districts in areas adjacent to his route of travel. He returned from this trip benefited not only in health, but mentally stimulated by the companionship of his associates and by the examples he saw of new applications of science to constructive empire-building.

Closing Days

On the completion of his office work, during the winter and spring of 1923-24, he again went to Alaska and visited several of the Survey parties in the field. As he was no longer able physically to undertake strenuous exertion, however, he had to content himself with visiting the more accessible camps. In spite of his physical infirmity, he was as much interested as ever in Alaska and gladly drew on his wealth of information to aid his associates or the prospectors and miners in the solution of their problems. He returned to Washington early in October, 1924, and with his characteristic vigor plunged at once into his accumulated office duties. When his associates entered his room, after office hours, on November 21, they found that, without any premonitory warning, he had collapsed at his desk. Almost at once he became unconscious, and in less than twelve hours he had passed away. He had just completed an article on "The future of Alaska," which he was to deliver at the Brooklyn Institute of Arts and Sciences the next day, and had lantern slides packed and everything in readiness to go to Brooklyn in the morning. It was a trip to which he had looked forward with much pleasure, especially as he was to be accompanied by his wife. Doubtless, the strain of completing the article, which he felt contained things that "must" be said about Alaska, was the last burden that proved too much for his already overtaxed body. It was, however, the way in which he would have liked to make the supreme sacrifice.

An attempt has here been made to trace in more or less chronological sequence the larger events in Brooks's life. The composite story told by these events is a story of extensive travel and experience, enormous productivity, and innumerable personal contributions to science and to the work of his associates. Some measure of his productivity is afforded by the bibliographic list of his writings that is appended to this sketch. That list, however, tells only part of the story, because every publication that was prepared under his administration of the Alaskan work bears the imprint of his criticism and constructive comment. During the

period that he served in the Alaskan work the Geological Survey published over 380 reports and over 420 maps, covering more than 235,000 square miles of exploratory or reconnaissance topographic mapping and 220,000 square miles of geologic mapping, each equivalent to nearly 40 per cent of the entire area of Alaska—a monumental achievement whose energizing force came in large measure from Brooks.

The foregoing facts, however, give only a clue to the personal qualities and charm of the man. He was of medium height, stockily built, of ruddy complexion, his hair and beard sandy until somewhat bleached and thinned by advancing years. He enjoyed walking, and, in addition to his tramps while engaged in field-work, during the last 15 years, made a practice while in Washington of walking daily from his home to his office, a distance of more than three miles, regardless of the weather. Other than this he took part in practically no other form of athletic exercise, though for some years he was interested in fencing, belonged to a fencing club, and engaged in bouts as time and opportunity permitted. He was not deft with his hands, and therefore found no pleasure in manual tasks that serve many men as an antidote to mental work. He lacked to a surprising degree the gaming instinct. Cards, games of chance, or competitive contests not only failed to interest him, but bored him nearly to distraction. He did enjoy the theater and found in it occasional relaxation. His greatest joy, however, was in conversation, no matter with whom or on what subjects, provided the talk was informative and the participants presented interesting, authoritative, or novel views. He would sit up until late in the night, in his home or in the field, talking with friends and associates. Those who have traveled with him on a long ocean voyage all bear witness that he was the center of an animated group, discussing problems and always having something to say that was well worth hearing. Probably his love of conversation was due to the fact that he was always alert to learn, and that he found this a sure method of accumulating knowledge. He was an omnivorous reader and loved to collect books. As a young man in college, his greatest single item of expense was for the purchase of books, and he was always loath to throw away even a circular that he had received.

Brooks's method of writing was in many ways unique. He dictated very little, but instead wrote voluminously in a large, rather illegible hand. The activity of his thoughts usually far outstripped that of his pen, so that many of his sentences and even some of his words were incomplete. The remarkable feature of his work, however, was that he did not go over these drafts in detail, changing a word here and there, transferring sections or amplifying ideas, but instead he practically dis-

regarded the first draft and wrote another, almost as if it were brand new and original. The mere task of having reduced his thoughts to written words seemed to clarify his expression and to perfect the arrangement of his later drafts. In this way he would frequently rewrite an article three or four times, leaving the correction of minor details, such as spelling and punctuation, mainly to his secretary. This practice kept him from becoming wedded to an expression simply because he had once written it in a certain way, and undoubtedly improved his style, making it terse and pointed, so that the reader was never in doubt as to his meaning.

Conclusion

Perhaps the most outstanding quality of Brooks was his intellectual honesty—honesty of purpose, honesty in the methods he practiced, and honesty in the support of the conclusions he reached. This quality is all the more remarkable because in exploratory work, whether that term applies to broad explorations in a new country or in a new realm of thought, there is neither time nor opportunity for the same minute scrutiny of details as there is in a restricted investigation in more thoroughly cultivated fields. In fact, the successful explorer must paint with broad strokes and bold outlines. Brooks did this, always leaving the picture clear and distinct, but at the same time, because he realized the necessary imperfections in his data, he pointed out those features that should be accepted only tentatively and that might require supplementary touching up or actual redrawing.

Whether his intellectual honesty expressed itself through his humor, or *vice versa*, is as inconsequential as the age-long question of which was first, the hen or the egg. Certain it is that his appreciation of the humor of a situation or the ludicrousness of a proposition gave him a poise that made him an excellent counselor, who was never swept off his balance by sophistry or self-deception. It was his humor or his intellectual honesty that prevented his spelling science with capital letters and worshiping at the shrine of a pure science, undefiled by application to human needs and served by acolytes who speak in language unintelligible except to the elect. It was his humor that made him an agreeable companion and conversationalist or an opponent to be feared. His was a kind humor, however, that was not employed to hurt or antagonize unjustifiably the object toward which it was directed, and it was never used to be "smart" or "clever."

He had a disciplined and well-stocked mind that was by no means of "meteoric" or "inspired" quality. All that he got was won through hard

work and unremitting application. This naturally prevented him from making glittering generalities and snapshot judgments himself, and made him distrust the soundness of the work of others who indulged in these practices. He required of himself hard work in the field, hard work in the study, and hard work in expressing carefully and accurately his conclusions, in order that he might measure up to his standards of intellectual honesty. He naturally measured others by similar standards, though he never was a driving taskmaster to his subordinates. It was, perhaps, the hard work by which he reached his conclusions that prevented his readily changing his opinions when formed. This characteristic sometimes resulted in his continuing to place values on the work of some of his associates that were not always in accord with the opinion of others equally competent to judge critically.

In a tribute paid to the memory of this great scientist, Doctor George Otis Smith has said:

"The one word best describing Alfred Brooks is loyal. He was loyal to those he loved, his family, and his friends. He was loyal to his science and to the organization of which he was a member for nearly 30 years. He was loyal to his chosen field of activity and to his country. This unswerving allegiance, the outstanding trait of the man, translated itself into abiding friendships, devoted service, and effective patriotism."

We do not differ with Doctor Smith as to the facts or as to the accuracy of the term "loyal" to describe Brooks. We would go further, however, and suggest that loyalty was another manifestation of the intellectual honesty of the man, who, seeing clearly his relation to himself, to his family, to his associates, and to his country, accepted the responsibility that this knowledge implied and met it to the limit of his ability.

With all the honors and regard that came to Brooks from learned societies, from those highest in administering the affairs of the nation, from his associates, from every Alaskan, Brooks's intellectual honesty prevented him from ever becoming self-important. He never strove to get into the limelight and never pushed himself or his ideas forward. When his opinions were asked he was always glad to express them frankly, but he never expressed them in a way that could be called oracular. Of the many charming illustrations that might be given of the innate modesty of the man, the following statement, taken from his letter acknowledging the congratulations of his associates on the completion of 25 years of service on the Survey, is perhaps the most appropriate one with which to close this sketch of Brooks of Alaska:

"Were the day clear I could see Mount McKinley from the window. As I picture in my mind its stupendous height, I compare it to our science. Many

have assailed its flanks; some have proclaimed untruths about it; some have climbed by great effort well up the slopes; a very few, the best by natural selection, have reached the summit and there attained the broad vision denied those at lower altitudes. As for me, I am satisfied to have been able to traverse the great lowland to the base and to climb the foothills."

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Photograph by Bachrach

John M. Clarke

MEMORIAL OF JOHN MASON CLARKE [1]

BY CHARLES SCHUCHERT

In the death of John Mason Clarke, paleontologists and geologists mourn the loss of a brilliant, eloquent, and influential colleague, whose work on the Devonian is felt everywhere, but most strongly in North and South America and in Germany. Author of some 450 papers and books, totaling about 10,000 pages, his efforts had to do mostly with pure science. As an organizer of a State museum he had no equal, and as director of a State geological survey he maintained the long-continued preeminence of New York. As a lover of the beautiful and the significant in nature, he originated public parks, commemorated good work and striking events in science by the erection of bronze tablets, and wrote the history of human settlements in the picturesque land of Gaspé.

Clarke was peculiarly the child of his environment. Born of a father who was a lover and teacher of nature, and in a village whose rocks are replete with Devonian fossils, he began collecting the latter when he was but six years of age, and they became the things of which he knew more than any other man. In the councils of science he stood at the top in his native State and was among the leaders in the nation. These facts have long been recognized, as shown in the many honors given him at home and abroad.

Clarke's yeoman ancestors came to America early in the year 1630, on the sailing vessel *Mary and John,* which set its 140 passengers ashore at Nantasket, near Hull, Massachusetts. In this party was William Clarke, who, with his wife Sarah, settled at Dorchester in 1636. Here were born to them ten children, with all of whom they moved to Northampton in 1663. The line then comes down to the fifth William, who was a member of the Continental Congress, fought at Lexington and at Bennington, and after the Revolution moved by oxcart to western New York, where he was one of the founders of the town of Naples. The ninth child of William Clarke the fifth, born at Windsor, Connecticut, in 1787, was Lorenzo Clarke, whose second child, Noah Turner Clarke (1817-1898), was the father of the subject of this sketch. His mother was Laura Mason Merrill, of Castleton, Vermont, a descendant of the *Mayflower* company and of Governor Jonathan Trumbull, of Connecticut. Six children were born of this union, of whom the fifth, John Mason, first saw the light in the beautiful lake resort of Canandaigua on April 15, 1857.

[1] Manuscript received by the Secretary of the Society December 28, 1925.

The present writer became acquainted with Clarke in the autumn of 1889, when he also joined Hall's staff at Albany, but as his private assistant. Then ensued delightful Thursday evenings with Clarke and his family, when we discussed our favorite fossil brachiopods and exchanged remarks about the doings of our strenuous chief. What glorious evenings of inspiration these were! When the writer, later on, went to Washington, he still met Clarke two or three times each year, and our letters were frequent, and this close comradeship was continued to the end. We saw each other for the last time at the 1924 meeting of the Society at Ithaca, and Clarke's last letter, written May 14, 1925, was in his characteristic vein, but with an undertone of possible seriousness ahead, since he was then in the hands of his physician. Indeed, he devoted the last few days before going to the hospital to adjusting official matters between himself and his staff, and made suggestions to the regents of the Museum regarding his successor.

Suffering with a malignant growth of the bowels, Clarke was taken to the hospital for surgical treatment, and died after the fourth operation, on May 29, 1925. On the beautiful afternoon of June 1 a throng of his friends and fellow-workers assembled in Saint Peter's Presbyterian Church, in Albany, to listen to its significant services and to pay their last respects. Clarke now lies in the Rural Cemetery, where also sleep James Hall, Ebenezer Emmons, R. P. Whitfield, and Philip Ast, all members of the New York State Geological Survey.

Clarke is survived by his wife, formerly Mrs. Fannie V. Bosler, of Philadelphia; by Noah T. Clarke, a son by his first wife, who was Mrs. Emma Sill, of Albany (née Emma Juel, of Philadelphia); by two stepdaughters, Miss Marie Bosler and Mrs. Edith (Sill) Humphrey, and by a stepson, Mr. Frank N. Sill. Out of a family of five brothers and sisters, four remain to mourn his going, namely, Miss Clara Mason Clarke, who, with Mr. S. Merrill Clarke, for many years city editor of the New York *Sun*, is living in the homestead at Canandaigua; Rev. Lorenzo Mason Clarke, pastor of the First Presbyterian Church of Brooklyn; and William B. Clarke, managing editor of the Baltimore *American*.

During the sixty-first convocation of the University of the State of New York, the evening of October 15, 1925, was devoted to memorial exercises for Clarke, the speakers being the president of the university, Frank Pierrepont Graves; the Honorable William G. Rice, State civil service commissioner, and Charles D. Walcott, secretary of the Smithsonian Institution. The last-named said in part:

"New York State owes to Dr. Clarke an eternal debt of gratitude for preserving the records of its scientific activities of ninety years or more, and for

developing and carrying on, as a part of the educational system of the State, a museum unexcelled among State museums. James Hall, the founder of the museum and the great scientific leader of New York State for fifty years, died with the impression that there was no one who would take sufficient interest to carry it forward as an educational factor in the life of the oncoming generations of the people of the State. He did not fully realize that the young man who had been associated with him for years had all the qualities essential to successfully sustain the work of the world-renowned State Geological Survey and the upbuilding of a model State museum. Dr. Clarke, by birth, training, ability, and spirit, was the ideal successor of James Hall, and it is to the honor and credit of the regents of the university that they recognized his ability and fitness for the task and assigned it to him. Dr. Clarke effectively carried on a most important and valuable work, yet so quietly and modestly was it done that even those closely associated with him did not fully realize the contribution that he was making to science and to the reputation of the people of the State. His passing is a distinct loss to scientific interests in America, and to intelligent humanity throughout the world. The influence of such a personality extends through the medium of kindred minds to the men and women and to the boys and girls who are to be the future leaders and guardians of the material and spiritual welfare of the people of every nation."

Personality

Clarke stood between five feet nine and ten inches, was sparsely built, and probably at no time weighed more than 150 pounds. Dark of complexion and blue of eye, he had a well-balanced head and face, with a thin head of dark hair. In earlier life he wore a small mustache, but later on his face was cleanly shaven. Probably his most striking facial feature was his flashing blue eyes, which portrayed much of the momentary, but decided, feelings of the inner man, set, as they were, in a countenance that, even though rarely sad or stern, was not a smiling one. Ambitious, jealous of the New York Devonian, perhaps unduly suspicious at times, strong in likes and dislikes and quick of temper, he was easily aroused, and his face, and especially his eyes, changed with his mood. However, he usually had these phases of his make-up under good control. He was a great tease, and especially brilliant in the company of ladies, delighting in the give and take of repartee, in which he was rarely outdone. He was richly endowed with imagination, which had full play in his last book, "L'Île Percée" (1923). Of sarcasm he had much, and woe unto the man who angered him into action! Always proper in dress, eloquent in speech, pleasing in manner, and deliberate in his acts, he moved easily in society, with the unconscious ease of one to the manner born.

Mentally, Clarke was brilliant, alert, orderly, and well trained. Always a lover of the worth-while in life, the beautiful in nature and art,

and always a hard worker, he quickly became a prodigious producer of excellent paleontologic and stratigraphic results. These qualities made of him also a collector of antique ceramics and furniture and historian of the fisherfolk of Quebec. They are likewise reflected in the unusual character and excellence of the museum under his direction, which is probably his best monument.

Clarke's ideals in science were of the highest and his leanings were decidedly toward pure science rather than toward the applied aspects. At times he was very outspoken in this matter, lamenting that so few geologists nowadays go into science solely for the love of the work, and that most men take up the subject as a means toward a better living. This, of course, will always be so in most cases, and yet there is no denying that the tendency in the United States has long been alarming, especially since 1914. Ever since the World War our universities have found a marked dearth of good men to take up teaching, and the surveys look in vain for leading geologists and paleontologists. Accordingly, to make himself felt in this matter, Clarke at times overstated the situation, hurting his friends and sometimes giving rise to sad feelings. He fully understood, however, that the mining world can pay higher salaries to good men than the universities and surveys, and it can not be said of him that as director of the Geological Survey of New York he neglected to develop the natural resources of the State. Certainly he did for the mining and engineering world much more than stands to the credit of his predecessor, James Hall.

The nearly century-old New York State Survey and the somewhat younger Museum have long been under the guidance of the Regents of the University of the State of New York, but the appropriations for their maintenance have to come through the New York Assembly. Therefore both Hall and Clarke saw much of the regulation statesmen and their humorous, if not always wise, ways of doing things for science. Hall rarely was the gentle mixer with people, but his great prestige in science generally assured him success with the Assembly. Clarke, on the other hand, had the gift of making eloquent addresses and of easily meeting men of importance, while his caution in keeping abreast of coming events among the powers that are and are to be made him a tower of strength behind the regents. He was, therefore, much more successful in making things possible in the Science Division of the University than any of his predecessors. For the Museum he got, in addition, much money from private sources, which was used in making striking exhibits, ranging from toadstools to habitat groups of Indians, and

from restorations of marine animals to the astonishingly beautiful one of the Gilboa Devonian forest.

Youth and Rise into Geology

Clarke's father was for fifty years a teacher of science and for nearly thirty years principal in the Canandaigua Academy. The boy John not only had his schooling in the academy building, but was actually born there. The father's first experience in geology, at the age of 21 (1838), was gained from Eben N. Horsford, who was then assistant to James Hall, geologist of the Fourth District of New York. In 1870 the elder Clarke found a nest of Upper Devonian crinoids, one of which Hall named after him (*Melocrinus clarkei*). The Clarke family, therefore, had been interested in the geology of New York ever since the organization of the Survey by Governor Clinton.

As a small boy of six, Clarke began collecting "cows' horns" and "shells" in the garden soil about his home, and when he was ten years old his father gave him copies of Hugh Miller's "Old Red Sandstone" and Hitchcock's "Text-book of Geology." The texts were too much for the boy, but the pictures of trilobites interested him greatly, and one day he called his father to come and look at one of the cornerstones under the house, in which he had found both a "Silurian trilobite" and a "Devonian trilobite"! Clarke then goes on to say, in notes that he has left concerning himself, that he continued collecting in a desultory way, as the inspiration caught him, but the pursuit did not become productive until he had learned how to use the "Paleontology of New York." This was in the early seventies. "My home region was most beautifully supplied with the objects of my search; the shale cliffs along the shore and the ravines of the lake teemed with fossils."

In 1874 Clarke was sent to Amherst College, but it was not until his junior year, when he reached the course in mineralogy under Prof. C. U. Shepard, that his "suppressed love broke out in full force." The next year he came under the influence of that distinguished maker of geologists, Benjamin K. Emerson, and "had a new birth."

The first year out of college (1877-1878) he taught in the academy at home and worked on the local geology. "I had now become methodical," he says. "I collected from the Hamilton rocks, plotting the vertical range of every species, and these to the number of 300 to 400. On this basis I sought to establish a zonal division of these strata by faunules."

In the autumn of 1878 Clarke was called to Amherst as assistant to Professor Emerson, and to arrange the great C. U. Shepard and C. B.

Adams collections of minerals and recent shells. The following year he was back again at the Canandaigua Academy, and his collections grew "to commanding proportions." In the autumn of 1880 he became teacher of science in the Utica Free Academy, but it was in 1881 that came the first significant appointment in his career, namely, that as instructor in geology, mineralogy, and zoology at Smith College. Professor Emerson writes me: "I taught in Smith from the beginning. Clarke was my assistant for a time, and as he seemed to need a place I got President Seelye to appoint him in my place." At the end of the college year 1883 Clarke got leave of absence to go to Germany to begin work toward a doctorate in science. To Göttingen and Professor von Koenen he went that summer, and "these days," he says, "made history for me and will ever be filled with happiest recollections." On his return to Smith, in the autumn of 1884, he found that conditions had changed, since President Seelye, accusing him of heterodoxy, closed with the statement that his services were no longer needed. This sudden blow cut short Clarke's hopes for continuing his studies at Göttingen and getting the coveted Ph. D. degree in course. This year, therefore, he lectured on geology and zoology and taught German at the Massachusetts Agricultural College at Amherst. Then followed days of waiting during the summer, which he spent at Canandaigua, continuing to work on the Upper Devonian, mainly the Naples series. Out of employment, he appealed to James Hall, whom he had known since 1875. His persistence was finally rewarded, through the strenuous insistence of a State senator, and on January 1, 1886, Clarke became assistant to the man who was then the master paleontologist of America.

Clarke's entry into Hall's service is described in his "Life of James Hall" (1921) in the following humorous way:

> "In the autumn of 1885 I came to Albany . . . to show to Professor Hall and Mr. Beecher a quantity of new things in trilobite and crustacean lines which I had been extracting from the Devonian rocks in western New York. . . . The trilobites made so effective an appeal that I was to join the force at once and trust to good luck to edge my way into the service. On the first of January, 1886, 9 o'clock in the morning found me in front of the great stove in Mr. Hall's 'office' on the Beaverkill, trying to dry my soaked clothes after a rough tramp of two miles through a foot of freshly fallen snow. No one else was there; but presently the ruddy Santa Claus of Hall's figure coming in from breakfast appeared through the door and with a gray look of surprise in his spectacles, as he saw me by the stove, he said: 'Oh, yes. How do you do? How do you do? Could you lend me two dollars?' Then began my association of twelve years with this extraordinary man [then 75 years old], whom I had known slightly for ten years past, but whose equations I had yet to learn."

From January 1, 1886, until his death, on May 29, 1925, Clarke was connected with the Geological Survey of New York, rising to the position of State Paleontologist in 1898, and in 1904 to that of State Geologist and Paleontologist and Director of the State Museum and of the Science Division of the Education Department. From 1894 on he was also Professor of Geology and Mineralogy at the Rensselaer Polytechnic Institute in Troy, New York.

Museum Career

As has just been mentioned, Clarke was in 1904 made Director of the Science Division of the University of New York and of the State Museum. This was the most significant appointment in his life, since now he had inherited not only the whole of Hall's official mantle, but a great deal more, and all of it, under his guidance, grew quickly into large proportions. The staff was soon more than doubled. He says: "This position involved not only directorship of the State Museum, but as well of the research departments in entomology, botany, zoology, and archeology." His time had now, therefore, to be divided between his own special scientific interests and the creation of a new State museum.

The needs of the rapidly growing museum collections and of the other divisions of the university brought about the construction of the large Education Building, which was completed in 1913. In the autumn of this year the State Museum began to move into its new quarters—that is, the entire upper floor, with 60,000 square feet of space, one-half of which is devoted to geology and paleontology. The opening of the building took place on December 29, 1916, before the assembled geologists of the country, who were addressed by Theodore Roosevelt. This was the proudest day in Clarke's life. New York now has the best State museum in America, with the finest array of highly significant Paleozoic fossils. From the paleontological side, it possesses one of the world's most valuable collections, containing upward of 7,000 type specimens and constituting a Mecca to which all students of the older Paleozoic go for inspiration and interpretation. Clarke also inaugurated the plans for the museum's artistic and lifelike restorations of Ordovician, Silurian, and Devonian marine assemblages found in New York State, and this type of installation and teaching had its culmination one day in February, 1925, when he placed before the public a reproduction of the Gilboa Devonian forest, a living picture of the oldest known forest to clothe Mother Earth.

Clarke had yet greater ambitions in the way of a State museum, and he wanted it to be an edifice worthy of New York and housing only its

things scientific and historical. Toward this end he had large preliminary drawings prepared and demonstrated them to the assembled geologists during the Albany meeting. Roosevelt also saw the plans at that time, but when the New York Assembly, during the winter of 1922, had under consideration a memorial building to the State's great son, to be erected either in New York City or in Albany, the decision went to the American Museum of Natural History. This was the hardest blow that Clarke ever received and one from which he never recovered. As Walcott said in his memorial to Clarke:

> "He felt most keenly and grieved to the end of his life that the effort to deprive the capital of the State of a great memorial to its former governor and foremost citizen of his time, Theodore Roosevelt, should have been successful."

Clarke was also interested in supplementing the museum collections by having set aside under its jurisdiction "unique or remarkable bits of geological scenery of high educational value . . . endangered by the progress of settlement or industry." He began this movement for the protection of natural monuments in 1908, and his first result came five years later with the gift of 350 acres to establish Indian Ladder Park, Albany County, where the actual base of the Devonian can be studied to best advantage. Soon followed Lester Park, near Saratoga, with its striking Upper Cambrian Cryptozoon ledges; the Myron H. Clark Reservation, a glacial park near Syracuse, showing the effects of glaciation and the former presence of falls that were nearly as grand as Niagara; and the Starks Knob Reservation, near Schuylerville, with the Northumberland volcano, long since extinct. There are now six of these parks or reservations under the administration of the New York State Museum.

State Survey

While Clarke had charge of the State Survey (1898-1925), with the aid of a competent staff nearly one-half of New York was geologically mapped on the scale of one mile to the inch, and the mineral wealth of the State exploited. Summoning to his assistance the best experts available, and issuing something like seventy bulletins, he brought the knowledge of New York geology, its rock structure, its marvelous fossil record, and its mineral industry to a condition that makes it safe to say that no equal area (50,000 square miles) in America is so completely known and understood. Among those who did most of the work should be mentioned D. Dana Luther, James F. Kemp, H. P. Cushing, R. Ruedemann,

W. J. Miller, H. L. Fairchild, H. P. Whitlock, D. H. Newland, J. B. Woodworth, A. W. Grabau, G. H. Chadwick, etcetera

Gaspesia

No sketch of John M. Clarke, either man or geologist, would be complete without recording the second great passion of his life, that for his beloved Gaspé. Attracted first to this far eastern portion of Quebec by the promise of geologic riches, he found besides a land of vivid beauty, discovered by Cartier in 1534, and peopled by fisherfolk whose simplicity of living and traditions of hospitality spell peace to men weary of the strife of the marketplace. It was not strange, therefore, that he returned to Gaspé summer after summer for nearly twenty years, tramping its shores for three hundred miles, and living among the people of the coast; so that few knew the country, its human history, and its natural science, as did this its adopted son. His interpretation of the geology is dealt with later in a discussion of his scientific work, but here we may pause to mention the two books in which his mastery of style finds itself at its best—both born of Gaspé. Few regions of the earth have had so ardent an interpreter, in whose pages the wonders of the geologic past, the marvelous beauty of land and sea, the stately days of the Seigneury, and the quaint customs of the present day mingle with equal warmth and color. "The Heart of Gaspé," published in 1913, and the even more charming "L'Île Percée" of ten years later constitute an important contribution not only to history, but to literature as well.

In studying the history of Gaspé, Clarke helped to locate the site of the old French custom house occupied by the intendant, M. Reval, and destroyed by Wolfe in 1758, and to dig out from the sands of the peninsula where it stood the relics of the old régime, now in the Château de Ramezay. From Cap des Rosiers he took the Cartier medallion, and from Bonaventure Island he had the old freebooter Duval's cutlass, with its gold-plated brass mountings and its beautifully damascened and inlaid blade carrying the royal arms and monogram of George III heavily worked into the hilt.

Clarke's interest in old china also found a new field in Gaspé and, as he says, "led to the acquisition, at a time when no one else was interested, of a large collection of the old wares of the people." His publications on ceramics include "English Gold Lusters" and "The Swiss Influence on the Early Pennsylvania Slip Decorated Majolica," both privately printed at Albany in 1908.

Clarke also actively concerned himself to arouse provincial and Federal interest in the preservation of the waterfowl nesting places on Percé

Rock, Bonaventure Island, and the Bird Rocks of the Magdalen Islands. He visited the Magdalens frequently and wrote accounts of their geology and history. In recognition of his interest in Gaspé, the Quebec Board of Geographic Names in 1917 attached his name to a township covering the upper reaches and great salmon pools of the Grand Cascapedia River.

Other Public Acts

Clarke's strong historical sense is again seen in his placing of memorial tablets. This began in 1901, when he and a few others placed on the home of Ebenezer Emmons, on Hudson Avenue and High Street, in Albany, a tablet commemorating the fact that in this house, in 1838-1839, was started the Association of American Geologists, the parent body of the American Association for the Advancement of Science. In 1908 he placed one in Letchworth Park, near the Portage cataracts on the upper Genesee, to commemorate the first geologic work done by James Hall in western New York, in 1839 to 1843. Five years later, through his efforts, Logan Park was set apart in Gaspé, and here he unveiled, before the geologists of the Twelfth International Geological Congress, a bronze tablet memorializing Sir William Logan's pioneer field-work in eastern Canada. In 1916, at the meeting of the Association of American State Geologists, a tablet was placed on Hall's private museum in Beaver (now Lincoln) Park, in Albany.

Clarke was always much interested in the welfare of the city of Albany. Here he did much to rehabilitate the Albany Institute, one of the oldest scientific societies in the country, and was its president for many years. He was also president of both the Historical and Art societies, and they thrived greatly under his care, as did also the Burns Club and the Walter Scott Memorial Association. He helped and cheered on the good work of the ladies of the Dana Natural History Society, was a trustee of the Schuyler Mansion, and after 1916 of the Dudley Observatory. A member of the Fort Orange Council of the Boy Scouts, as well as of the National Council, he arranged for the Mayflower Medal, to be awarded each year to the scout having the best knowledge of the local history.

Clarke's championship of the need of preservation of scenic beauty by the State was best exemplified in the case of Niagara Falls. He says:

"The claim of the higher life, the demands of the finer emotions, the love for the beautiful in nature, express themselves in part in the government protection of natural wonders from defacement and destruction; in organizations created to keep alive this sentiment and extend the ægis of the State over natural glories which belong to mankind rather than to men. No wise

man confesses himself devoid of such emotions. The violation of this principle in present practice offends the best sentiments of the race."

Clarke was among the first to point out the "menace to Niagara" contained in the threatened destruction of the scenic beauty of the Falls, in part if not wholly, by the power companies located along the banks of the river. This danger was long seen coming, and in 1904 the fight against it culminated in the New York Assembly. Clarke stood out in opposition to it, and in public addresses and otherwise pointed out that "the conservation of Niagara Falls is a question of public morals." This battle, in which Clarke played so large a part, was won and a treaty has been made with Great Britain keeping the water of the Falls under reasonable control.

In 1902 Clarke was delegated by the Geological Society of America to represent the Society at the dedication of a memorial to Hugh Miller, the Scotch quarryman, newspaperman, and geologist, who had been in large measure the inspiration of his youth and for whose memorial, the Hugh Miller Museum at Cromarty, in northern Scotland, he had raised a considerable sum from Miller's American admirers. At a later date, and as an appropriate cis-Atlantic memorial to Miller, Clarke proposed the name "Hugh Miller Cliffs" for the Devonian fish beds on Scaumenac Bay, Quebec—a name which was accepted by the Quebec Geographic Board.

Biographies

Of biographies of geologists and paleontologists, Clarke wrote at least twelve: of G. H. Williams, Beecher, Laflamme, Whitfield, N. H. Winchell, H. C. Hovey, Prosser, W. B. Clark, James Eights, Cushing, James Hall, and Sir Archibald Geikie. The tribute to his old chief, "James Hall, of Albany, Geologist and Paleontologist," a book of 565 pages, appearing in 1921, is in a class by itself. James Hall was a youth of 25 years when he entered the service of New York, and an old man of 87 when he left that service. In his biography Clarke portrays "the man as he was; the influences that guided him and that he imparted; the work he did and the manner of doing it; the friendships he made and the esteem he won." Written in an animated style and eloquent in diction, replete with humor and anecdote, it tells not only what manner of man Hall was and the tremendous amount he accomplished, but also the men he worked with and those with whom he came into direct contact. It is, in fact, one of the two best contributions to the history of North American geology and paleontology, set in a background of these sciences in Europe. Reading it, we are forced to the conclusion that New York

State truly has been the mother of geologists. The writer's review of this book in *Science* pleased Clarke, and he wrote me in one of his characteristic letters: "If you don't get your reward on this earth, I'll try to arrange matters with Saint Peter so that we can sit together."

Honors

Of "honors which beautify and crown success," Clarke had many. Four times he received calls from leading universities to take chairs in geology, and with better salaries than he had at Albany (Ohio State, 1898; Columbia, 1900; Yale, 1904; and Pennsylvania, 1919), but each time he declined, saying that his work was in New York. To his commonwealth he gave his best as a loyal son, and he was deeply grateful for the liberal support she gave him in return, as appears again and again in his annual reports.

Clarke was elected to something like fifty scientific and historical societies in this country, Canada, England, Germany, France, and Russia; made an Immortal in the National Academy of Sciences in 1909; elected to honorary membership in the American Philosophical Society, the American Academy of Arts and Sciences, the Geological Society of London, the Authors' Club of London, and the Société Russe de Minéralogie. He was elected Vice-President of the Geological Society of America in 1909 and its President in 1916; made first President of the Paleontological Society in 1909; awarded the Prix de Léonide Spindiaroff of the International Geological Congress in 1910 for his work in Gaspé; awarded a gold medal by the Permanent Wild Life Protection Fund (1920), the Hayden Gold Medal of the Philadelphia Academy of Natural Sciences for excellence in geological research (1908), and the Thompson Gold Medal of the National Academy of Sciences in 1925.

Of honorary degrees Clarke also had many. He regarded as the most important of these the honorary Ph. D. conferred upon him by the University of Marburg in 1898. The degree of Sc. D. was given him by Colgate in 1909, by Chicago in 1916, and by Princeton in 1919; and the LL. D. by Amherst in 1892 and by Johns Hopkins in 1915. Finally, Prof. Charles Barrois writes me that it had been the intention of the French Academy at its next meeting to elect Clarke an honorary fellow.

Work on Paleontology and Morphology

After five summers in the field, Clarke began to show results, and his first three papers appeared in 1882, during his instructorship at Smith. They have to do with a rare species of the living mollusk *Gundlachia*,

and with rare specimens of Crustacea—phyllocarids and barnacles—from the New York Devonian. Arthropods were, therefore, his first love among fossils, and they continued all through his life to have for him a dominating interest. In these earliest papers he bursts upon the scientific world, as it were, as a full-fledged descriptive paleontologist, since they show nothing of the beginner; even then he wrote well, in a clear and direct fashion, that, however, showed none of the phrase-making, quaintness, love of strange words, and power of embellishment and atmosphere so characteristic of his later writings.

With Clarke's appointment to the New York Survey, his career as a paleontologist and stratigrapher was assured, and from his head and hand there came a continuous stream of the best kind of geologic publications, the great bulk of which have to do with Devonian paleontology and stratigraphy and were issued by his native State. The bibliography compiled by his son Noah and appended hereto, enumerates 380 titles, of which about 300 are of a paleontologic or geologic nature, and there are, in addition, 70 reviews not here listed. Together Clarke's printed books and papers cover over 10,000 pages, in which he is godfather to some 135 new genera and about 870 new forms; but how many species of fossils he studied will probably never be tabulated. At least 3 genera and 42 species have been named after him.

Clarke was born on Devonian rocks and they ever remained the magnet of his endeavors. "The work of a geologist is preeminently what his environment makes it." The strongest pulls were those of New York, southeastern Quebec, and Brazil; but he was also attracted by the Devonian of Maryland, Falkland, and Argentina. Probably three-fourths or more of his total output has to do with the paleontology, stratigraphy, and mapping of this period. He long ago became one of the two greatest world authorities on the Devonian, the other being Emanuel Kayser, of Germany. Clarke's study of the Upper Devonian faunas of Iberg, Germany, was written at Göttingen, while a student of Von Koenen, and it was at this time that he became acquainted with Kayser. His loyalty to these two teachers of his is shown in his contributions to their Festschriften: "Evidences of a Coblenzian invasion in the Devonic of eastern North America" (1907) to that of Von Koenen, and to that of Kayser, "Conceptions regarding the American Devonic" (1915).

BRACHIOPODA

Shortly after Clarke got to Albany (1886) he became deeply interested in work that Beecher was then doing. It appears that in 1878-

1879 C. D. Walcott made extensive collections for the New York State Survey at the famous Silurian locality in Waldron, Indiana, sending Hall about seven tons of fossils and slabs. In washing this material, Beecher saved all the freed dirt, and so got together a large quantity of minute specimens. Beecher and Clarke, working by lamplight, night after night, during the years 1886-1887, picked out of these washings about 50,000 baby brachiopods, with lengths ranging from less than 1 up to 5 millimeters. Finally, they culled out 15,000 good examples, which they separated into twenty species, each abundantly represented by specimens. Arranging these into growth or ontogenetic series, they then studied out the appearance of the specific characters. Their results are set forth in "The development of some Silurian Brachiopoda" (1889). This is probably the first ontogenetic work on fossil brachiopods, and, while it was of an elementary nature, it prepared both authors for a better appreciation of their later studies on this class of organisms. Probably the most striking result was that the inceptive shells, of whatever species, were smooth, only slightly convex, and had a subcircular outline. This led Beecher later on to the discovery that all brachiopods start in life with such a shell, which he called the protegulum; and, since the nearest fossil mature forms are of the genus Paterina (Iphidea), he also called the protegulum the "Paterina growth stage" in brachiopods.

When Clarke had completed the work on the Devonian Crustacea in 1888 (see page 63), Hall asked him to take up a revision of the species of the Paleozoic Brachiopoda, but the young man had in mind a greater and a more philosophic work. Their joint planning resulted in a turning away from a study of fossil faunas to a genetic one having also to do with the phylogeny and evolution of an entire class. It was in search of material for this work that Hall came to Cincinnati late in 1889, and, seeing the writer's large and well arranged collection of brachiopods, proposed that he come to Albany as his private assistant and allow him the use of his collection. This arrangement lasted about two and one-half years.

Our combined labors resulted in the comprehensive study entitled "An introduction to the study of the genera of Paleozoic Brachiopoda," by Hall and Clarke ("Paleontology of New York, volume VIII," 1892, 1894). In this memoir 146 old genera are redefined and 61 new ones added. As a by-product came the description of 57 new species. While these books were in press, the study was extended to a synoptic revision of all the brachiopod genera, extinct and living, along with a summation of the known anatomy of the soft parts in the living species and their bathymetric and geographic distribution. The results of these extended

labors appeared in two octavo volumes under the title "An introduction to the study of the Brachiopoda intended as a hand-book for the use of students" (1892, 1894). This reworking showed that the class had at least 329 genera and subgenera worthy of recognition. These four books treating of a class that has lived at least since the beginning of Cambrian time form the most comprehensive study ever made on a class of invertebrate fossils and represent Clarke's highest attainment in morphologic and phylogenetic work. His results have stimulated researches on these organisms throughout the world, so that today there are by actual count not less than 620 recognized genera or subgenera of brachiopods.

CRUSTACEA

When Clarke began his official work under Hall in 1886, he was set to work on his pets, the Crustacea. This study resulted in the memoir "Devonian Crustacea," usually spoken of as "Paleontology of New York, volume VII" (1888), by Hall and Clarke. In this volume, which included much new material that Clarke had collected in earlier years and brought with him from his home, are described 144 species (50 new) in 28 genera (9 new). Of these, 127 are of the Devonian and 83 forms in 10 genera are of trilobites, among them highly ornate and gigantic types, the last of a rapidly declining stock. Of this volume Clarke in 1921 said:

> "This book on the Crustacea was a substantial descriptive work which has served well, but it attempted nothing serious in the way of classification; it did, however, establish some interesting facts in development or ontogeny."

SPONGES

Then came what is regarded as the final volume in the series known as "Paleontology of New York," entitled "A memoir on the Paleozoic reticulate sponges constituting the family Dictyospongidæ," by Hall and Clarke, begun in 1884, but not published until 1898. Here are described and figured all the late Devonian and Mississippian forms representative of the living "glass sponges," of which there are 128 species. It is mainly in New York that the great fossil "sponge plantations" occur. Of new subfamilies there are 7, of new genera 22, and of new species 75. It is the most elaborate study of Devonian sponges.

EURYPTERIDS

The most detailed morphologic, ontogenetic, and phylogenetic study made by Clarke is the joint memoir with Ruedemann on "The Eurypterida of New York" (1912). It is only locally that these fossils are common; and yet thousands of specimens were assembled, probably more

than had ever before been brought together, with the result that North America was seen to have 62 species (26 are new), 46 of which occur in New York. No locality in America has ever yielded more material of this interesting group than that in the Bertie (Silurian) at Buffalo, New York. They ranged from the Upper Cambrian into the early Permian and were marine animals into the Silurian. Later on they were able to live in both salt and brackish water, and finally, throughout the Devonian and Carboniferous, they were small and scarce animals that lived wholly in fresh water. "Some were best adapted to swimming, others to crawling, and many to finding their food by grubbing in the mud."

Clarke and Ruedemann had specimens as small as 2 millimeters in length, and the ontogeny of the group was shown to agree with that in *Limulus*. Neither line had any direct relationship with the trilobites, and their origin probably goes back to the Proterozoic; the trilobite-crustacean and arachnid lines may have had independent origins in chætopod annelids.

Work on Paleontology and Stratigraphy

Silurian-Devonian boundary

While Clarke was a student in Germany a lively discussion was centering about Professor Kayser, who had in 1878, 1881, and 1884 raised the question as to the actual boundary between the Silurian and Devonian. The founder of these terms, Murchison, had established neither a top for the one nor a base for the other. In 1889 Clarke spoke to the writer about the "Hercynfrage," saying that he was writing an account of it, and that, as he saw it, the Lower Helderberg was the base of the Devonian in America. But how to get this paper by our watchful chief, with his quite different views? Long afterward (1915) Clarke wrote:

> **"Hall was so absolutely hostile to the suggested interpretation that in order to even secure publication for this array of evidence it became necessary to change a possible argument into a neutral statement of facts and all conclusions into queries."**

Hall, however, published the paper in 1889, and the writer was converted to Clarke's view, namely, that the Lower Pentamerus limestone (Coeymans) and not the Oriskany, as had long been held by Hall and De Verneuil, was the base of the Devonian system of rocks. Clarke returned to the discussion in 1891 and 1894, holding "that the fauna of the Helderberg division is not Silurian is demonstrated; that it is consequently early Devonian is a *non sequitur*." It was not until 1900

that the writer got a chance to take his stand on the question in print. His paper in the Bulletin of the Geological Society of America led to another controversy, a triangular one between Clarke and Schuchert on one side and Henry Shaler Williams on the other, and it was as a result of this discussion that the two former made the visit to Gaspé, of which more is said elsewhere. The storm clouds have, however, long since blown away and the Coeymans is the accepted base of the Devonian in this country. On this basis the boundary in continental Europe is now also adjusted, but in Great Britain, where the Devonian system started, the geologists are still trying to adjust themselves to the views of the rising generation, namely, that the Ludlow closes the Silurian, while the remaining "Silurian" is in reality Devonian.

ORISKANY FAUNA

In 1892 Beecher found on Becraft Mountain, near Hudson, New York, a new locality of Oriskany sandstone and one far more varied than any heretofore known in the State. This discovery Clarke elaborated and in 1900 presented his conclusions in the memoir "The Oriskany fauna of Becraft Mountain, Columbia County, N. Y." Here are described 113 species, 13 being new. About one-fourth of the fauna is from the Helderbergian below and ten forms go into the Middle Devonian. The faunal characteristics of the Helderbergian were also analyzed, with the result that everything from the Coeymans up is definitely referred to the Devonian, while a review of the Manlius biota shows that it is still clearly of the Silurian.

GUELPH FAUNA

Until 1903 it was not known to what extent the Guelph faunas occurred in the Lockport limestone of New York, but in that year a great deal of material, brought together by several collectors, was elaborated in the memoir by Clarke and Ruedemann, entitled "Guelph fauna of the State of New York" (1903). Here the Lockport is shown to contain two distinct faunas, an older indigenous one, the outgrowth of the Rochester below, and the Guelph immigrant fauna, which pulsated two or three times from elsewhere into the upper half of the Lockport. These recurrent Guelph faunas have 71 species in New York, of which 14 are new. It is a fauna composed dominantly of thick-shelled mollusks and some brachiopods, which lived in a shallowing and vanishing, warm, dolomite-making sea surcharged with salts. The authors trace the extent of this seaway and conclude that the fauna is of northern origin.

DEVONIAN OF GASPÉ

As was said above, the writer in 1900 became involved in a controversy with H. S. Williams as to the lower boundary of the Devonian, while Clarke a few years earlier had assembled Oriskanian fossils from beds in northern Maine that were said by Williams to be Silurian. Both of us had read the work of Logan and Billings ("Geology of Canada," 1863) on the very long "Siluro-Devonian" section of Gaspé Peninsula, in Quebec, where the Silurian is said to pass unbroken into the Devonian. We therefore arranged to see this wonderful record during the summer of 1900. Together we first visited the coast of Arisaig, Nova Scotia; then Dalhousie, New Brunswick, where Clarke began to get interested, and this interest grew as we went on to Percé, Quebec, and finally to Gaspé. We then concluded to divide the work between us, Clarke to take the Oriskany equivalents and the writer the Helderbergian and Arisaig faunas. In the end, however, Clarke worked out the whole of the Devonian, since there is no Silurian involved in the Gaspé section, while Schuchert, through his students, described the Arisaig Silurian sequence and its faunas.

On this trip of 1900 Clarke told the writer that he had found in Gaspé what he had long been looking for—a land of quaintness, reminding him of Scotland and the Old Red, both lands of red sandstones and of fish, fossil and recent. His visit there reawakened in him the memories of his boyhood days and his reading of Hugh Miller's popular books in geology. To this part of the maritime provinces of Canada, therefore, Clarke returned nearly every summer from that year on and became the high priest of its geology.

After Clarke's adoption of Gaspé in 1900, he published at least fifteen papers and books on the paleontology of that region, and his two-volume quarto, "Early Devonic history of New York and eastern North America" (1908, 1909) is his *magnum opus*. These two volumes of upward of 600 pages and 100 plates treat of the Lower Devonian stratigraphy and faunas of Quebec, New Brunswick, and Maine, fitted into the older background of the equivalent formations of New York and the Appalachian geosyncline. In this faunal study he was concerned with over 700 species and described about 450, of which 160 are new. We do not see here that degree of paleontologic refinement shown in his earlier "Naples fauna." The stratigraphy and geologic structure of eastern Canada are, however, far more difficult than those of central New York, and, in addition, he was dealing with Lower Devonian faunas and their intricate seaways throughout a spread of about 1,500 miles. And even this is not all, for the faunas were also viewed in the light of those of western Europe.

Clarke concludes that during Helderbergian and Oriskanian times the Gaspé seas were faunal generating centers that dispersed their life southwestward through the Saint Lawrence and Appalachian troughs, but that in Hamilton time the migrations were reversed.

The Gaspé sequence of strata, as defined by Logan, has a thickness of 2,000 feet of limestones, divided into eight divisions and followed by about 7,000 feet of sandstones. The two basal divisions have come to be known as the Saint Alban limestone (160 feet thick, with a fauna of 51 species), which is followed by the poorly fossiliferous divisions 3 to 6, now called the Cape Bon Ami limestone (1,050 feet, with 11 species), and then by divisions 7 and 8 = Grande Grève limestones (800 feet, with 150 forms). The Saint Alban series correlates with the Coeymans and New Scotland of New York, while the Grande Grève is mainly Oriskany with some Onondaga. The overlying Gaspé sandstones have, about 1,000 feet above their base, an unmistakable Hamilton fauna (48 species, of which 14 are new), but higher, the fossils are scattering land plants and fishes that do not as yet give the exact age of the upper strata of this thick sandstone sequence, other than that they are Upper Devonian. Then followed intense mountain-making—the Acadian Mountains—and the accumulation of the Bonaventure land conglomerates, to depths ranging up to 1,500 feet, in the structural valleys now occupied by the Bay de Chaleur.

All in all, "Early Devonic history of New York and eastern North America" is not only Clarke's master work, but also one of the most comprehensive faunal studies that we have in this country, showing Clarke to have been one of the world's best stratigraphers.

NAPLES FAUNAS

As Clarke intended to go to Germany for a doctorate after he should be graduated from Amherst, he began thinking in his senior year (1877) about subject-matter for his dissertation. The Portage group had been thought to be very poor in fossils, but as he and D. D. Luther had been finding many of them in these beds, Clarke concluded to take up a detailed study of these strata and their contained faunules. His final results appeared in 1898 and in 1904, under the title "The Naples fauna in western New York." In the meantime he had written sixteen other papers on this stratigraphic unit and its fossils. One of these has a great deal of stratal detail not in the two final papers—a fact which should be borne in mind by the student; it is entitled "The stratigraphic and faunal relations of the Oneonta sandstones and shales, the Ithaca and the Portage groups in central New York" (1897). In Clarke's "Naples

fauna" we have one of his two best memoirs on faunal and stratigraphic studies, and one of the best examples that can be set before a worker as an ideal toward which to work.

The Naples fauna is characterized by *Manticoceras intumescens*, which occurs throughout the 600 feet of strata situated near the base of the Upper Devonian. It is a part of the Portage group and occurs in two facies—(1) black shales and (2) sandstones—which alternate with one another several times. To the east was land, while to the west occurred deepest water, and the Naples fauna becomes disentangled from the shore faunas at the meridian of Cayuga, and is absent at the west end of the State. It is a distinct biota occurring in the western or Genesee province of New York, while to the east is first the Ithaca and then the Oneonta province. The life is peculiar in that it is chiefly of the floating and swimming types, in the main bivalves (cardioconchs and Lunulicardia), cephalopods, especially goniatites, and gastropods and pteropods. In all there are 153 species, as follows: pelecypods, 72 (52 new); cephalopods, 37 (25); gastropods, 26 (14); brachiopods, 7; and scattering, 11. The work yielded 37 new genera. Clarke says that the warm-water element, the Styliolina faunules, came in from the south, while the main part, with the goniatites, came in from the northwest with a colder water that "laved the northern and eastern shores" of the Appalachian Gulf, and that "the proximal path of its migration lies buried beneath Lake Erie." Finally, that at least the goniatite elements of the Naples fauna had their origin in Timan (arctic Siberia), spread thence down the Cordilleran geosyncline into the Genesee province, and from there eastward to Europe. That there is this direct European linkage with the "intumescens fauna" is seen in 18 species in common with the Genesee province, along with at least 19 others having close relationships.

DEVONIAN-CARBONIFEROUS BOUNDARY

Regarding the upper boundary of the Devonian, Clarke expresses himself fully in "Construction of the Olean rock section" (1903). He says that the Carboniferous fossils appear at the base of the Cattaraugus in the Wolf Creek conglomerate, and it is in fossils that "we have the support of the most direct evidence."

NEW YORK DEVONIAN AS THE WORLD STANDARD

Finally, what the New York Devonian means in the general setting of the period throughout the Americas and Europe, Clarke sets forth in a paper written as a tribute to the great *Devonkenner* of Europe, Prof. Emanuel Kayser, on his seventieth birthday. The Devonian of New

York, he here shows, should be the standard of reference throughout the world, since New York

> "is very properly designated a Devonic State, for more than one-half its area is covered by the rocks of the period, and the succession of its members from base to summit comprises a record whose pages are almost intact and effectively illustrate the variant happenings of the time. . . . Not in Devonshire nor in the Rhineland, not in the Urals nor in Siberia, not on the Bosporus or in South Africa, not in the basin of the Amazon, of the La Plata or in the Andean Cordilleras, is the full and variant succession of Devonic events so well recorded or at least so clearly and simply presented, and perhaps so fully known, as in New York."

DEVONIAN OF SOUTH AMERICA

A few years after Clarke joined the New York Survey his friend, Orville A. Derby, of the Brazilian Geological Survey, who was by birth also a New Yorker, asked him to describe certain Silurian and Devonian fossils. This beginning led to eleven publications between 1890 and 1919, totalling some 600 pages and 37 plates, with descriptions of 260 species, of which 131 are new, along with the establishment of 14 new genera. Of these forms, 21 (16 new) are Silurian, all the rest being of the Lower and Middle Devonian. "Fosseis Devonianos do Paraná" (1913) brings together all that is known of the Devonian faunas in South America and Falkland. The Silurian and Devonian of the Amazon region are of one faunal province and have relationships with North America, while the Lower Devonian of southern Brazil, the Andes, and Falkland is of the austral province and distinctly linked with South Africa. These works show that Clarke put into order and brought up to date the whole of the Devonian faunas of South America. With them and his far more extensive studies of the Devonian of New York and Gaspé, we are now able to understand the relationships of the Devonian of the New World to that of Europe, Asia, and Africa.

The Philosophy of Clarke, the Paleontologist

The philosophy gained by Clarke out of his paleontologic studies is to be found mainly in five of his papers, namely, his address to the Paleontological Society as its first President (1911); "The philosophy of geology and the order of the State," being his presidential address to the Geological Society of America in 1916 (1917); "Postbellum reflections on the place of paleontology among the sciences" (1920); "Organic dependence and disease," published in 1919 and 1921; and "The age of the earth from the paleontological viewpoint," read before the American

Philosophical Society in 1922. His conception of what the life of the past should teach the living world may be summed up as follows:

"Paleontology is . . . the most far-reaching of all the sciences. In it lies the root of all truth; out of it must come the solution of the complex enigmas of human society. . . . It is the panoramic display of the life of the ages, the expression of the organic law of a hundred successive worlds" (1910).

"I regard as peculiarly a doctrine of paleontology . . . that of recapitulation . . . the fact that each individual carries in himself and his development history the history of the race to which he belongs, however accelerated or however retarded it may be" (1916).

"The problem as to how species have originated . . . does not belong to paleontology." Students, both those of living organisms and of fossil ones, "see the engrossing fact of evolution, but see it out of different eyes; the former perhaps as one would see a vast throng gathered together to acclaim a momentous event, a great victory or a high armistice; the latter as an endless army marching by, its vanguard already out of sight in the mists of the horizon, stragglers along the way falling back or giving up in hopelessness, while the interminable procession ever emerges out of the shadow" (1922).

"The standards of our best civilization are not those which have been derived from a clear apprehension of the paramount law," the biologic law. All animals in nature are born free, but not all are "born to an equality of opportunity." "Equality of opportunity in paleontology and in human history would mean a world of life with the chief factors of evolution eliminated. . . . If there had been equality of opportunity through the ages of paleontologic history, there would be no men in the world today" (1920).

The greatest significance of evolving life as seen throughout the geologic ages came to Clarke from his studies of the earliest phases of the parasitic or dependent conditions of life—a study of mutual organic associations that led to commensalism, sessility, and finally to parasitism, begun in 1908 and concluded in 1921. These degenerate modes of life involve

"the essential abandonment of normal, direct, upright living, and the benefactors thereby are types of life which Nature has cast out and aside as hopeless. . . . Individual and locomotive independence, then, it would seem, has been the major function and prime determining factor in the progress of life. . . . All progress in life, as reckoned in terms of man, has come through independence and through those lines of animal life in which independence has been maintained at any cost. . . . Rescue of dependents is, therefore, not a part of the scheme of Nature, except through the exercise of intelligence."

The paleontologist, looking at the record of life on the earth, says to the State:

"Be intelligently guided in the treatment of hereditary community parasites, defectives, congenital or confirmed misdemeanants, whatever the form

of degeneration may be, by recognition of the presumption that in so far as they can not be physiologically corrected, they are abandoned types in which there lies little hope of repair" (1916).

"Nature makes for the individual. . . . This truth is registered on the tablets of the earth. . . . Over and over again the dominant race has started on its career as an insignificant minority struggling for its existence against an overburden of mechanical and vital obstacles, armed only with specific virtue which have little by little fought their way into the foreground, and by so doing consummated their upward purpose. . . . The majority is purely numerical, while wisdom and truth may rest with the minority. . . . The voice of the people is not the voice of God."

Of English yeoman stock and among the first to enter by way of Massachusetts Bay to humanize the wilderness of North America, the ancestors of John Mason Clarke moved westward through three centuries, and, settling at Canandaigua, New York, gave rise to a teacher of the plain people in Noah Turner Clarke. Never bounteously blessed with the goods of this world, but rich in high ideals, he raised a family of leaders, and among them one of the greatest paleontologists of his time, a builder of museums, and a statesman of science. Upon a foundation of excellent English gained from home and college, he developed a language replete with interest, elegance, and conviction. A lover of Nature and of doers, he originated public parks and set up commemorative tablets to arouse the young to better things. He was one of the geniuses of science, "standing on the mountain top and catching the first rays of the rising sun."

Always a loyal son of New York, Clarke brought to the highest excellence the knowledge of its incomparable Devonian, and ever maintained the New York sequence of Paleozoic formations as the standard of comparison for eastern North America, and in general terms for all the world. It would be a great mistake, however, to think that his vision was limited to the Empire State, for his work in Gaspé was no less significant than that in the land of his nativity. Here, moreover, we see him not only as paleontologist and geologist, but equally influential in unearthing its human history and in the protection of its teeming bird life.

Clarke's period of descriptive and faunal work reached its climax in 1908-1909 with the publication of his greatest study, "Early Devonic history of New York and eastern North America," and during these protracted labors he was laying the foundations of his belief in what paleontology should mean in man's speculations concerning himself and his relation to the web of nature. Then, between 1908 and 1922, he formulated his conclusions, the gist of which is that we are all born free, but not equal in ability or opportunity; that socialism and com-

munism do not lead to the growth of the intellect; that all forms of human degeneracy should be carefully guarded by the State, and that the few seekers after knowledge, the guardians over "the jewel casket of the human race," must ever be ready to sacrifice themselves for the uplift of the majority, who are living the simple life, "the life that endures," though spiritually growing through slow accretion.

An intimate knowledge of the life of John Mason Clarke reveals that his path to eminence was hewn out with much labor, taxing to the utmost the many-sided training that was his from home, college, and environment. Gifted with marked intellectual powers, he used his talents to the full, steadily rising as paleontologist and stratigrapher, as museum administrator, philosopher, and historian. Above all, his life stands out as one of continuous service, service to his family and State, to paleontology and Devonian lore, and to his beloved Gaspesia.

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MEMORIAL OF RICHARD R. HICE

BY GEORGE H. ASHLEY[1]

Richard Roberts Hice was State Geologist of Pennsylvania for many years, including the duration of the World War, and will be remembered both for his official position and for his personality. Mr. Hice had a breezy, hearty manner that made him good company wherever he went. He rarely attended the meetings of this Society, and so was not personally known to many of its members; but his interest in the technology of clays and in the geology of his home region, his activities as a business man in western Pennsylvania, as a consulting geologist in the oil and gas fields, and as an orchardist in Florida, made him known to many in various professions who will cherish the memory of a gallant spirit, who, in the words of a favorite quotation of his, "with rapt admiration contemplates immortal Nature's ageless harmony."

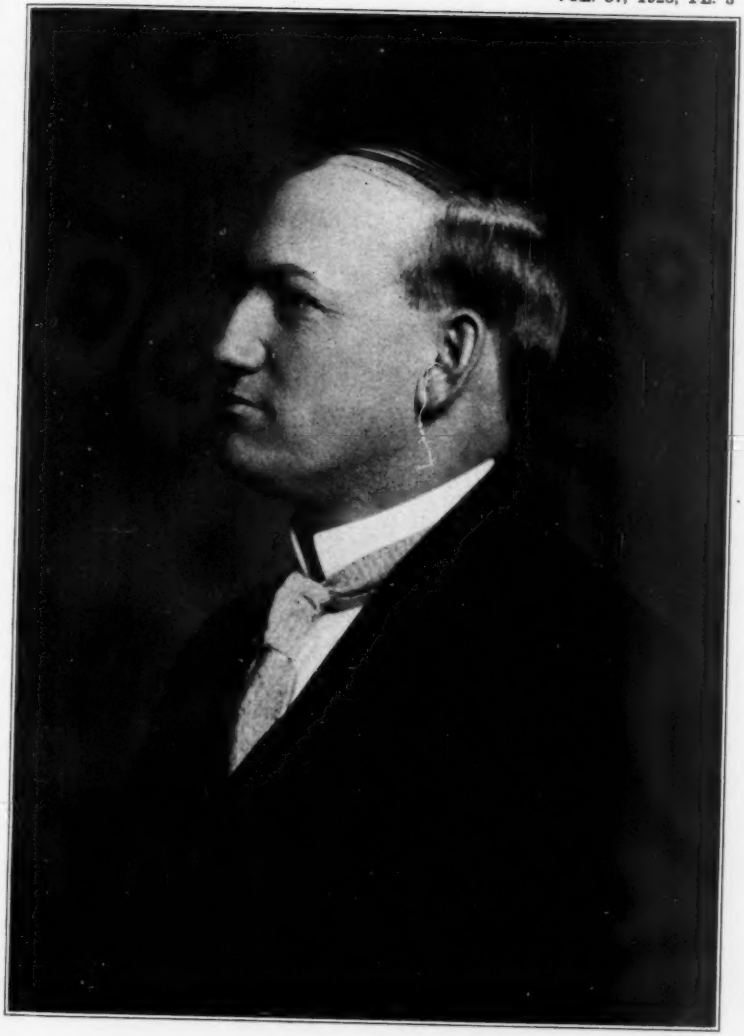
Richard Roberts Hice was born at Beaver, Pennsylvania, August 19, 1865, the son of Judge Henry Hice and Ruth Ann Ralston. His early education was in the Beaver public schools. In 1886 he graduated from Geneva College, from which institution he later received the degree of Sc. D. He married May Kells at Citra, Florida, April 12, 1893. They had one child, Eva Kells Hice, now Mrs. Ray W. Wakeland, of Fort Myers, Florida.

He was within six months of finishing his course in law when it was thought best for him to take up outdoor work on account of his health. He then became associated with one of the early gas companies of Beaver County, and later took up the manufacture of brick at Fallston, Pennsylvania. It was in association with this work that his interest in ceramics began to develop. He was one of the founders of the American Ceramic Society, one time president, and always had its welfare and interest at heart.

He was always interested in science, but especially in geology. His first writings were on preglacial drainage, a subject well illustrated by the physiography of his home county. He also wrote a number of other geological articles, some of which were published in pamphlet form and others in technical journals.

He was appointed one of the State Geological Commissioners of Pennsylvania, with George W. McNees, Andrew S. McCreath, and Edward V. d'Invilliers, and it was through the efforts of these men that in 1908 the Geological Survey of Pennsylvania was reorganized, with Mr. Hice as

[1] Manuscript received by the Secretary of the Society February 1, 1926.



Richard R. Hice

State Geologist. He continued in this position, with headquarters at Beaver, for about ten years, and then took up private work as a consulting geologist. He was deeply concerned about the conservation of the rapidly depleting supply of natural gas in his own State.

Mr. Hice was a Fellow of the Geological Society of America, a charter member of the American Ceramic Society, a member of the American Institute of Mining Engineers, the Engineers Society of Western Pennsylvania, the American Geographic Society, and the American Association for the Advancement of Science, and also a member of the Presbyterian Church.

Mr. Hice was probably as well or better known for his work in ceramics than for his studies in geology. He was a man of broad interests and a keen observer. His interest in astronomy at one time led Dr. John Brashear to ask his company on a solar expedition to Alabama. While State Geologist he conducted the delegates of the International Geological Congress through Pennsylvania.

During his term of office as State Geologist he often found it necessary to "carry on" without official funds, as the Survey suffered several times in having its appropriation vetoed when a retrenchment in State appropriations was necessary. This he did cheerfully, keeping up for a number of years the collection of statistics of mineral production of the State.

Under him as State Geologist were prepared and published the biennial reports of the Topographic and Geological Survey Commission of Pennsylvania, after that of 1906-1908, and a dozen reports, partly by himself, partly by others.

Mr. Hice had long been interested in Florida, especially in the utilization of the peat deposits of that State. When his strong physique gave way several years ago, as a result of influenza, he found it advisable to spend his winters at his home at Fort Myers, Florida, where he died March 27, 1925.

Among the geologic papers by Mr. Hice may be noted the following:

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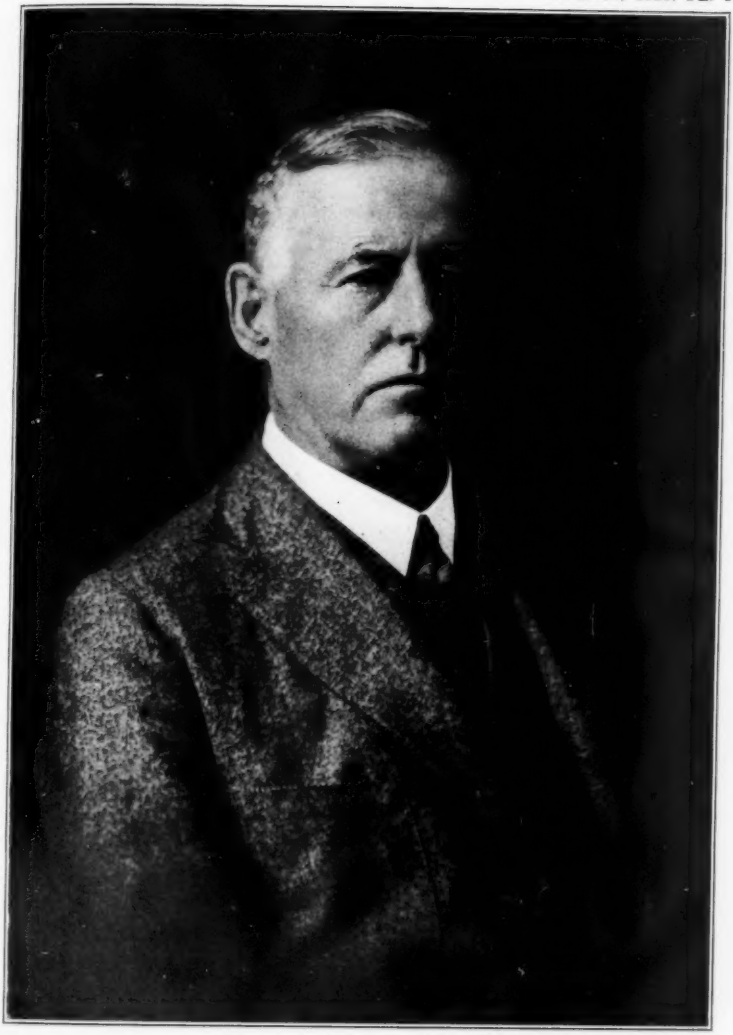
MEMORIAL OF WILLIAM MC INNES [1]

BY FREDERICK J. ALCOCK

William McInnes, whose death occurred at Ottawa, on March 10, 1925, was one of the outstanding figures in Canadian geology. For nearly forty-four years he was associated with the Department of Mines of Canada. As an active field worker for some thirty years, he contributed much to the geological and geographical information regarding some of the less known parts of Canada, and subsequently as Directing Geologist, and later as Director, of the Geological Survey of Canada, it fell to his lot to take charge, in an administrative capacity, of the activities of that branch of the department. In 1920 he was transferred to the position of Director of the Victoria Memorial Museum and Editor-in-Chief of the Department of Mines—an office which he held until his death.

[1] Manuscript received by the Secretary of the Society April 20, 1925.



William W. Ings

. Mr. McInnes was born in Fredericton, New Brunswick, on January 1, 1858. He received his early education in his native province, and in 1879 graduated as Bachelor of Arts from the University of New Brunswick. His geological field-work was begun in 1881, when he acted as assistant to Wallace Broad in western New Brunswick. In the following year he was appointed to the staff of the Geological Survey of Canada.

The early years of his geological field-work were spent in New Brunswick, first as an assistant to, and later as an associate with, Dr. L. W. Bailey, in the study of the Paleozoic formations of that province. He worked in this field until 1889.

In 1890 he began field-work in western Ontario, and from then until 1901 he carried out exploratory surveys in the country lying between Lake Superior and Lake of the Woods. The following three years were spent farther north in Ontario, in the region drained by the headwaters of the Winisk and Attawapiskat rivers.

In 1906 his work was shifted to Manitoba, along the proposed line of the Hudson Bay Railway, and from that year until 1910 his field-work consisted of reconnaissance geological surveys in the northern part of that province and in northern Saskatchewan. The results of these years of exploration were published in his memoir on the basins of Nelson and Churchill rivers, a work which still remains the standard source of information for much of that wide area of country.

In 1913 the Twelfth International Geological Congress was held in Canada, and in connection with the preparations for it there fell to Mr. McInnes the task of taking charge of much of the editorial work which it involved. He was one of the editors of the "Coal Resources of the World" and of the "Compte-Rendu" of the congress.

In 1915 Mr. McInnes was made "Directing Geologist in charge of all geological and field parties," and in 1919 he was made Director of the Geological Survey. In 1920, as has already been mentioned, he was made Director of the Victoria Memorial Museum and Editor-in-Chief of the Department of Mines.

Mr. McInnes was elected Fellow of the Geological Society of America in 1889, and Fellow of the Royal Society of Canada in 1912. He received in 1920 the honorary degree of Doctor of Laws from the University of New Brunswick.

He was a man who had the esteem of every one with whom he came in contact. He had a delicate appreciation of the finer things of life and was a man of wide reading. Of a retiring disposition, all advancement and honors came entirely unsought. In his dealings with men he showed a tact and sympathy which made him universally beloved. His loss is

especially felt by his colleagues, who knew his value and appreciated his worth.

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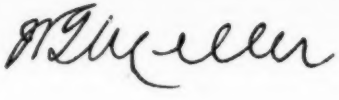

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MEMORIAL OF WILLET GREEN MILLER

BY JOSEPH B. TYRRELL[1]

One of the most appreciative articles on Dr. Miller, Provincial Geologist of Ontario, who died on February 4, 1925, said he had no private life. That was a tribute to the range and constancy of Dr. Miller's public service, but it was erroneous. Dr. Miller was a bachelor whose life was so private that even many of his nearest scientific friends knew next

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to nothing about it. Much has been written about his reserve, even to the extent to which sometimes he lapsed into silences that were almost repellent. Generally speaking, he was reserved. His speech was deliberate, even when it was free; but, like most big men physically who are also big intellectually, he was a delightful companion to those with whom he felt at ease. He did not care for the ordinary social exchanges really because, in its own way, his private life was extremely rich.

For the last thirteen years of his life we were neighbors. During most of that time ours was the only house he frequently visited, and I think I saw more of him than anyone else did during his last illness. He lived with his father and sister and his late mother, his devotion to whom was the truest measure of his personal quality.

Another writer has told how Dr. Miller postponed a trip because of his mother's illness, and showed a rare and strange emotion when giving the reason for the change. His mother was his goddess. At a banquet of the Canadian Mining Institute the story was spread around that he was engaged to be married. He felt it necessary to deny this impeachment, and explained that he was too old for that kind of romance, which everybody there would have liked to deny.

Miller, to the last, was not only a servant of the public in his official position, but also, uniquely, the servant of his friends. Shortly before he died I arrived home one evening about 10 o'clock to find a request from Miller to call him up on the telephone. He asked me to come over to his house. When I suggested that it might be too late, he said it couldn't be too late for him, as he had already had more sleep than he needed; and so we spent a couple of hours talking on the business that then interested him most.

He had just heard privately from London that his old friend and former assistant, C. W. Knight, had been awarded the Bigsby Medal by the Geological Society of London. He was uncertain whether the communication was confidential, but would like to surprise Knight by publishing the news in the Toronto papers before Knight received it officially. I suggested that the London *Times* be inspected to see if the awards of medals by the Geological Society were published in some obscure corner of that paper.

Miller was delighted at the honor which had come to Knight, and was as pleased over the plot to surprise his friend as a father is in filling stockings on Christmas Eve. Next morning his secretary found the item in the *Times;* Miller advised the Minister of Mines of the award, and the Minister passed it on to the newspapers. That, I believe, was how Mr. Knight learned that he had been given the Bigsby Medal

Nothing was more characteristic of Dr. Miller than this scheme, both as to the quality of its friendship and the correct attitude of a mind which did not want to forestall official news with confidential information. His answering letter to his London friend was the last he wrote.

As a public servant, Miller was kindness itself, but not too kind. The young fellows he has started on their careers by giving them something to do in his department or passing them on to others who could use them during their summer's freedom from study are legion. He was remarkably quick in deciding whether the applicant before him was suited to the job desired. Almost instantly, and without apparent effort to prove the capacities of his subject, he would decide as to his qualifications for service. I think very few men were right in their diagnoses of aptitudes as often as Dr. Miller was.

Miller never sought honors, but he was more jealous of the precedents of his department than many who came in contact with his quiet geniality might have supposed. That, no doubt, was inherent in the success of what was really a unique phase of modern government. I believe no State on this continent, or, indeed, in the world, has a more efficiently serviceable geological department than the Province of Ontario. Dr. Miller was the department; the department was Dr. Miller, for he was its first chief, and his official superiors, though they could give him support, could not furnish him with much guidance in a field of which, in some cases, their knowledge was not extensive, though it may have been peculiar.

During the twenty-three years that Dr. Miller was Provincial Geologist his immediate chief was T. W. Gibson, the Deputy Minister of Mines. The several ministers of mines during that period, though they were all deeply interested in the development of northern Ontario, where our mineral deposits most abound, were neither geologists nor miners. Mr. Gibson himself, though most competent and wide-minded in all matters of general administration and mining progress, never professed to be a distinguished geologist, which Miller most certainly was.

Miller, instead of being the dreamy, absorbed, unpractical wanderer among the rocks, with a heavy hammer and a heavy satchel, was one of the most practical correlators of the science of geology and the practice of extracting wealth from the rocks who has ever served modern science. He was a scientist who left a comfortable fortune, acquired without exploiting any of the spectacular opportunities which came his way, but by shrewd and quiet connection with enterprises out of which he did not desire to make fabulous wealth, but from which he was content to secure himself against the caprice of fortune.

Just as his scheme to surprise Knight was characteristic of his personal relationships, so his last will and testament was in keeping with his devotion to the progress of the great province of which he was so outstanding a citizen. Half his fortune was left to be divided between the high school at Port Rowan, the University of Toronto, of which he was a graduate, and Queen's University, of Kingston, of which he had been a professor.

Geology may not be the most intuitive of the sciences, though it is one of them. In one of the ablest of the Miller memoirs it is written that Dr. Miller was largely self-taught as a geologist. That is no doubt true, in the general acceptance of terms; but neither Dr. Miller nor anybody else could have taught him how to read the secrets of the rocks unless there had been in him the same inexplicable aptitude for his task that there is in the great poet, the great musician, and the great master of literature.

A genius for geology, such as Miller's was, can not be attributed to any known ancestry, in the same way that some people attribute virtue to the long continuance of a peerage, in which noblesse oblige has been supposed to be working, any more than a genius for discovering the possibilities of radio can have descended from a long line of radiographers. The geologist knows a great many things which he does not know how he knows. Some of them come to him in spite of, or, perhaps, as a part of, his unwillingness to study along purely conventional lines.

Miller's father, who survives him, was a farmer and lumberman near Forestville, Norfolk County, Ontario, a few miles from the shore of Lake Erie. He had been born at Burlington, at the head of Lake Ontario, in 1839, to which place his father had come from Plattsburg, New York, in 1821. His ancestors had been in the United States since 1634. Dr. Miller's mother, who also was born at Burlington, was altogether Scotch, her parents' town having been Jedburgh, near enough to the English border to give it and its children an almost fiercely Scottish tone.

Miller was, therefore, very North American, and also fundamentally Scotch, but he was not at first fond of the student's grind. At fourteen years of age he did not want to go to school any more, and his father let him have his way; but in about a year he asked to return to school, and thenceforward never refrained from study.

Something of the quietness which was noticed by all, and which sometimes rather appalled strangers, may have been due to the accomplishment in which he first achieved more than a family distinction. As a boy he was one of the best checker players in the county of Norfolk, which prided itself upon the skill with which it could make kings on the board.

From the public school he went to Port Rowan High School, where his teacher was A. G. MacKay, remarkably successful as a teacher and afterwards distinguished as a lawyer and politician. MacKay became Minister of Mines in Ontario a couple of years after his old pupil had been appointed Provincial Geologist. From High School Miller went to the University of Toronto, where he studied under Professors Chapman, Pike, and Ramsay Wright, and from which he graduated in 1890 with first-class honors in mineralogy, geology, and zoology. He spoke always with the warmest appreciation of Chapman. While he was at varsity the family moved from Port Rowan to Toronto; so that, except during the time he was professor at Queen's University, his private life in this city was about as ideal as that of a studious bachelor scientist devoted to his mother could be.

From 1890 to 1893 Miller was a fellow in mineralogy and geology in Toronto and taught these subjects during the autumn and winter. In summer he acted as assistant to Dr. Robert Bell, of the Geological Survey of Canada, spending his vacations in the classic Huronian area north of Lake Huron. In 1893 he went to Queen's School of Mining in Kingston as lecturer. He afterwards became professor in Queen's University, and so remained until 1902, when he was given two years' leave of absence, to act as the first Provincial Geologist of Ontario. The principal of Queen's was Dr. Grant, the most distinguished of all the college presidents whom Canada has not exported to the United States.

Dr. Grant, though not a geologist, was very sympathetic to geological work, and often spoke of the value of Professor Miller's habit of taking parties of his students into the rocky and picturesque country north of Kingston, showing them minerals in place and bringing them into personal contact with geological problems and conditions. Miller never missed an opportunity of speaking with admiration and enthusiasm of Principal Grant's leadership, and of his remarkable gift for attaching his students to himself and to their studies.

In 1894 and 1895 Miller took short postgraduate courses in his special subjects at the universities of Chicago, Harvard, and Heidelberg. From 1897 to 1901 he carried on geological work in Ontario for the Ontario Bureau of Mines, mainly in special investigations on corundum, iron ore, and gold in the eastern section of the Province. It was this work which led directly to his appointment as Provincial Geologist.

Of Miller's professional originality perhaps the first outstanding example was given to his friends when he was a young professor at Queen's, and a press dispatch reported the discovery of X-rays of astounding properties obtained from electric currents passing through a Crookes

tube. There was a Crookes tube in the laboratory, and Miller proceeded to experiment with a view to learning the effects of minerals on these rays.

Before getting satisfactory results the tube was burned out; but Miller secured another from the Royal Military College, and with it tested out Professor Nicol's collection of minerals. Except corundum, the minerals which were translucent and carbon minerals which were transparent all proved to be opaque to the rays.

No details of the X-rays technique had been given in the press dispatch, so that Miller was indeed a researcher in an unfamiliar field. He described his cheap, safe, and rapid test for diamonds, emeralds, corundum, and emery in the American Geologist. His method was quickly adopted by the trade, and this before the finely equipped scientific laboratories in the greatest American seats of learning could obtain the complete apparatus and instructions from Europe for repeating Roentgen's experiments.

Miller's first notable service as a geologist in aid of business was rendered through his work on corundum. Dr. W. F. Ferrier had recognized corundum as occurring in eastern Ontario, and Professor Miller investigated its occurrence for the Provincial Bureau of Mines. He worked out a new method in the field of discovery. The rock exposures of corundum are not numerous in eastern Ontario. When he had discovered the direction in which corundum-bearing rock seemed to be trending, he would travel southward, and then turn back to the north, watching for boulders of corundum-bearing rock in the glacial drift. In other words, he came upstream against the glacial flow, and where he found drift boulders he was usually close to the source of supply.

Miller was the first to use this method of prospecting in a glaciated country. It has since been followed advantageously in other places, and is now being used by the Geological Survey of Finland, which, apparently not knowing of its use in Canada many years before, has described it as a new application of glacial geology.

Corundum was suited to take the place of emery, but the process of making emery wheels was not applicable to it. A new method had to be found, and Miller discovered it in his attic at Queen's. Even then the market did not readily take to corundum; so that Miller went to the United States as a sort of pioneer among scientists and got the market. In due time, of course, carborundum superseded corundum, but that does not affect the great value of Miller's work as a scientist and practical man of affairs.

The creation of the short-lived corundum industry caused the Ontario Government to provide the School of Mining at Queen's, with *Ontario* Hall for its geological department, and also with a substantial annual money grant. Thus Miller's work directly secured for his successor infinitely better quarters than the attic in which, with much painful diffidence, he developed his ability as a lecturer to his students. It was out of this corundum work, too, that the position of Provincial Geologist arose, through which the mineral industries of Ontario had for twenty-three years the inestimable advantage of Miller's undivided time and interest.

When Miller became Provincial Geologist no precious minerals were being mined in northern Ontario. Indeed, the Timiskaming and Northern Ontario Railway was only just projected as a governmental colonization road, and a great many people thought that it was nothing more than an electioneering expedient.

Logan and George Dawson had both expressed themselves favorably on the prospects of finding valuable ore deposits in the pre-Cambrian rocks of northern Canada, and Miller was a supporter of their belief that the discovery of such ore deposits would reward anything like systematic prospecting. He was smiled at by many incredulous ones, but it was not long before his confidence received its first justification.

In the late fall of 1903 nicolite and smaltite were found on the railway right of way beside what was then called Long Lake, but has since become known as Cobalt Lake. Samples were brought to Miller. He immediately went north, going to Haileybury by boat from the end of the Canadian Pacific Railroad branch line to Mattawa, at the south extremity of Lake Timiskaming. Going over the ground, he found a boulder containing silver, the first recognition of silver in that region. Miller brought his find into Haileybury that night and did not keep the discovery secret.

Next morning the snow had come and, no thaw following it, prospecting operations were postponed until spring. Then Miller proclaimed his certainty that the Timiskaming and Northern Ontario Railway was destined to justify his and others' faith in the mineral resources of the North.

Reporters on the Parliament Buildings assignment, when news was scarce, would go to Miller in sure and certain hope of receiving something interesting about the North. Sometimes he said to them:

"If you boys don't want to die poor, you had better scrape together a hundred dollars and put it into some mining prospect along the Government railway."

I think there is no partiality of friendship in saying that Miller's place among geologists is with Logan and Dawson. He had more scientific knowledge to draw on when he started than the other two great Canadians had; but he was of their class in the extraordinary aptitude for his chosen work and for the mark he has left on the development of his country. He was more fortunate in directing commercial development, perhaps, than some of his contemporaries; but that does not detract from his unique service in a unique area of geological achievement.

Only in Michigan and Minnesota, surely, has there been anything like as intimate a study of pre-Cambrian rocks as Miller lavished upon those of Ontario. His first report on the Cobalt region is memorable for the breadth and accuracy of its information and for the sureness of its prophecy, which has been remarkably fulfilled in our time. It is not often that an official geological report runs into fourth and fifth editions, as this has.

From that time onward Miller kept in close touch with mineral development in northern Ontario, partly by personal observation, but more through the work of the small but very efficient staff of geologists which he had collected around him. He worked hard to assist in the development of his country's mineral resources. Much of his time was taken up with official and executive work, for his advice was sought by all who were interested in mining in the Province of Ontario; but he found time to write many reports and papers on the mineral-bearing areas of Ontario.

For his work in the development of the mineral wealth of the pre-Cambrian rocks he was awarded the gold medal of the Institute of Mining and Metallurgy of London, England, in 1915; but he always maintained his keen interest in the more purely scientific study of these rocks, as may be seen by a glance at the appended bibliography, and the nomenclature suggested or adopted by him for many of the subdivisions of the pre-Cambrian has already established itself firmly in geological literature.

Only a small proportion of the capital invested in Ontario mines has come from Great Britain. The present Government desires that more of the means of developing our mineral resources be secured from the Old Land. To that end Dr. Miller spent some time in England last year, and, *inter alia*, his notes for these lectures are before me. Nothing could more eloquently bear testimony to the range and thoroughness of a lecturer. The notes are copious and the original photographs of all the slides to be used are reproduced in order.

No wonder that Miller made a deep impression, not only on scientific

men over there, but on financial and business leaders with whom he came in contact. It is mentioned now for the first time that the Government's program was to have Dr. Miller spend about half his time in Britain, turning his remarkable geological knowledge of his own province to most practical account.

And that is the note which every appreciation of Dr. Miller must needs strike—the note of his special combination of scientific flair with practical sagacity, which made him a geologist among men of affairs and a man of affairs among geologists; and, above all, a friend *sans peur et sans reproche*.

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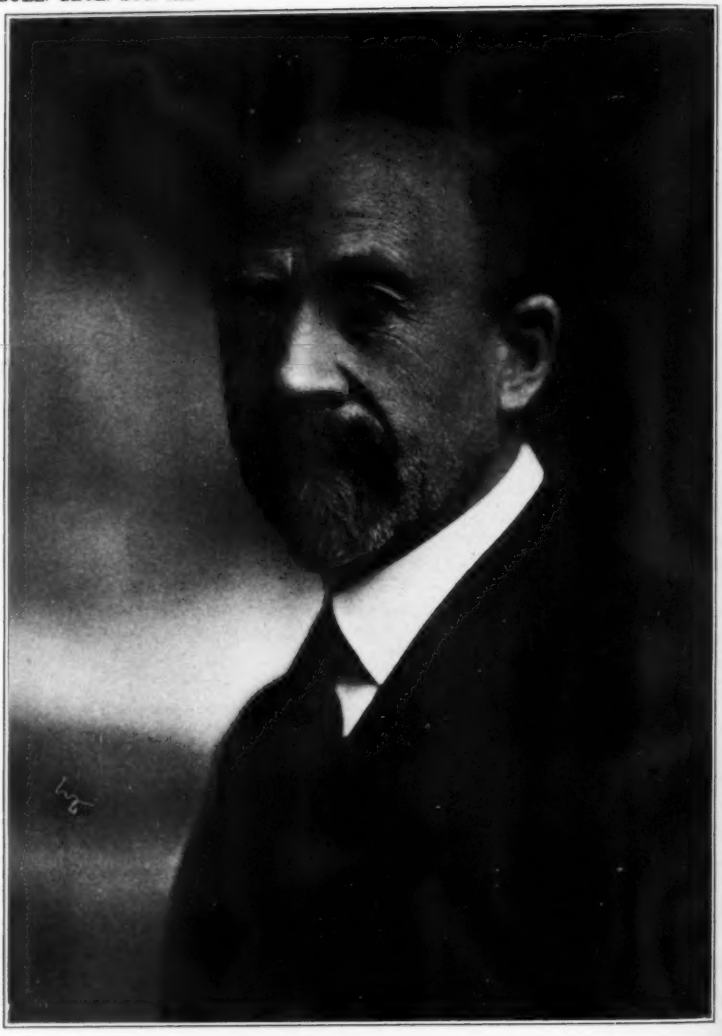

F. B. Peck

MEMORIAL OF FREDERICK BURRITT PECK

BY HERVEY W. SHIMER[1]

Frederick Burritt Peck was for the last 28 years Professor of Geology and Mineralogy at Lafayette College, in Easton, Pennsylvania. He was born in Seneca Castle, in central New York, on August 10, 1860, the eldest child of Henry Jones Peck and Mary Diantha (Gray) Peck. On his father's side he was descended from William Peck, a merchant of London, who came to America in 1637 and settled in New Haven. On his mother's side he was descended from Thomas White, who came over with John Winthrop in 1630. His ancestors in both these lines included men prominent in pioneer movements and in social reform, with tendencies toward scientific and philosophical thought. They were doctors, ministers, lawyers, merchants, and farmers.

His father was farmer, surveyor, and amateur geologist. During the winter he taught district school. It was in this school and amid these country surroundings that Frederick Peck received his early education. He then went to the academy at Canandaigua, New York, whose principal, Dr. Noah T. Clarke, was justly famed as an inspiring teacher. It was under his influence that young Peck was induced to go to Amherst College. There, brought into contact with Prof. B. K. Emerson, he soon chose geology as his special field.

While at the academy Peck formed a close friendship with the principal's two sons, John M. and A. Mason Clarke—a friendship which lasted throughout life. Two of this trio died within a few months of each other and are memorialized at the present annual meeting of the geologists of America.

Upon graduation from Amherst in 1886, with the degree of A. B., Peck went to Trinidad, Colorado, as teacher of mathematics and science in the Tillotson Academy. Here he remained for five years, holding the position of principal during the last of these years. During his vacations he made many geological and mining expeditions into the Rocky Mountains. These excursions gradually aroused in him a desire to learn more of the causes of what he saw and to get into more purely geological work; so in 1891 he returned to Amherst as assistant in geology. Here he remained for three years, from 1891 to 1894, teaching also at Smith College. The desire for further geological study drew him to Europe in 1894. He received the Ph. D. degree at the University of Munich in 1896. In Munich he plunged with insatiable eagerness, as far as his

[1] Manuscript received by the Secretary of the Society January 9, 1926.

student pursuits allowed, into the musical and other artistic life of that famous center. The zest for art and music which he then acquired he never lost. To the end of his life they were a never-failing source of recreation and happiness to his spiritual life.

When, in 1897, Lafayette College decided to establish a chair of geology, Dr. Peck was asked to fill it. He assumed his work with the title of Associate Professor of Geology. In 1901 he was advanced to full professorship, with the title of Professor of Geology and Mineralogy. This position he retained throughout the remainder of his life. Dr. Peck threw himself into his work at Lafayette with great ardor. Ethelbert D. Warfield, president of the college at the time of Dr. Peck's incumbency, supported his efforts very generously, and said in after years that the expectations and hopes concerning the new department had been fulfilled in the highest degree.

As soon, however, as the geological department had become well established, the great fire at Lafayette occurred, in which the largest of the scientific buildings, Pardee Hall, was largely destroyed and with it the collections and instruments of the geological department. Those of us who were there at this time know with what energy and wisdom Dr. Peck threw himself into the work of reparation, until he had built up a department second to none in teaching efficiency.

On June 12, 1901, Dr. Peck married Miss Cora Burr Horton, of Binghamton, New York. This proved an ideally happy and mutually helpful union.

He suffered in 1921 a nervous breakdown, from which he never fully recovered. On what proved to be his last appearance before the student body as a whole, a vesper service last winter, he discussed religion from the viewpoint of the geologist. His death occurred November 2, 1925. He is survived by his wife and one child, Mary Gray Peck, now a senior at Vassar College, and by a sister, Miss Mary Gray Peck, of Seneca Castle, New York. His brother, Dr. James Ingraham Peck, was Assistant Professor of Biology at Williams College at the time of his death, in 1898.

The courses taught by Dr. Peck covered a broad field, but they were not given superficially. His broad training and the study and research continued throughout life gave him a remarkable depth of knowledge. He was a frequent attendant at the meetings of the Geological Society of America and of other societies where research papers were presented. He often spoke of the stimulus given by such meetings. Geology for him was part of a wonderful whole in which man and nature were linked. The vision of life as an amazing march through the ages, from higher to

higher forms, humanized the teaching of this inspiring scientist. No pupil of his left his course without having had this vision presented to him.

Dr. Peck was a Fellow of the Geological Society of America, a member of the American Association for the Advancement of Science, the American Institute of Mining and Metallurgical Engineers, the American Association of University Professors, and the Pennsylvania Academy of Science. He served as Assistant Geologist on the United States Geological Survey from 1898 to 1909. He joined the Delta Upsilon fraternity at Amherst, and after coming to Easton became affiliated with the Lafayette Chapter. He was a member of the Brainerd-Union Presbyterian Church of Easton.

Dr. Peck was frequently consulted on mineralogical and geological matters by individuals and corporations from all over the country. His careful work on the local deposits of serpentine, talc, and cement, both as to their field relationships and their microscopic and chemical structure, made him a recognized authority on these rocks. He was asked by both the Pennsylvania and New Jersey geological surveys to write up these deposits for their reports and was similarly consulted by companies interested in these deposits from an economic point of view. In addition to this, the companies consulting him as an expert economic geologist covered a wide field of interests, for which he was well trained through his five years' experience in mining camps in Colorado and his later extended studies. For several summers preceding his breakdown, in 1921, he cooperated with George H. Ashley, State Geologist of Pennsylvania, in work on the Punxsatawney and Carnegie quadrangles, his last work being on the Vanport limestone in the Beaver Valley.

Notwithstanding the high quality of Dr. Peck's scientific work, it is especially as teacher and friend that he is best remembered by those who had the privilege of such association with him. He was a great teacher, and a large part of his success lay in his deep sympathy with and understanding of the student. His knowledge of the laws underlying the action of mind on mind seemed innate. It was probably a natural outgrowth of his sympathy.

He always approached his lecture or class work with enthusiasm, and this usually kindled a similar response in the student. He was quick to see our difficulties with the subject and had a clearness and directness of explanation, through which ran a kindly humor like a sparkling thread in a tapestry. His students loved him for his warm-hearted manhood and his kindly interest in their problems. He was distinguished by the unique honor of having two issues of the student annual dedicated to

him. His popularity extended to his colleagues at Lafayette and his scientific confreres throughout the world. All who knew him speak of his good fellowship, his strong character, and the patient and thorough way in which he did his work. He was a servant of Lafayette College who was an honor to her best traditions and a man who will be remembered with love by all who knew him.

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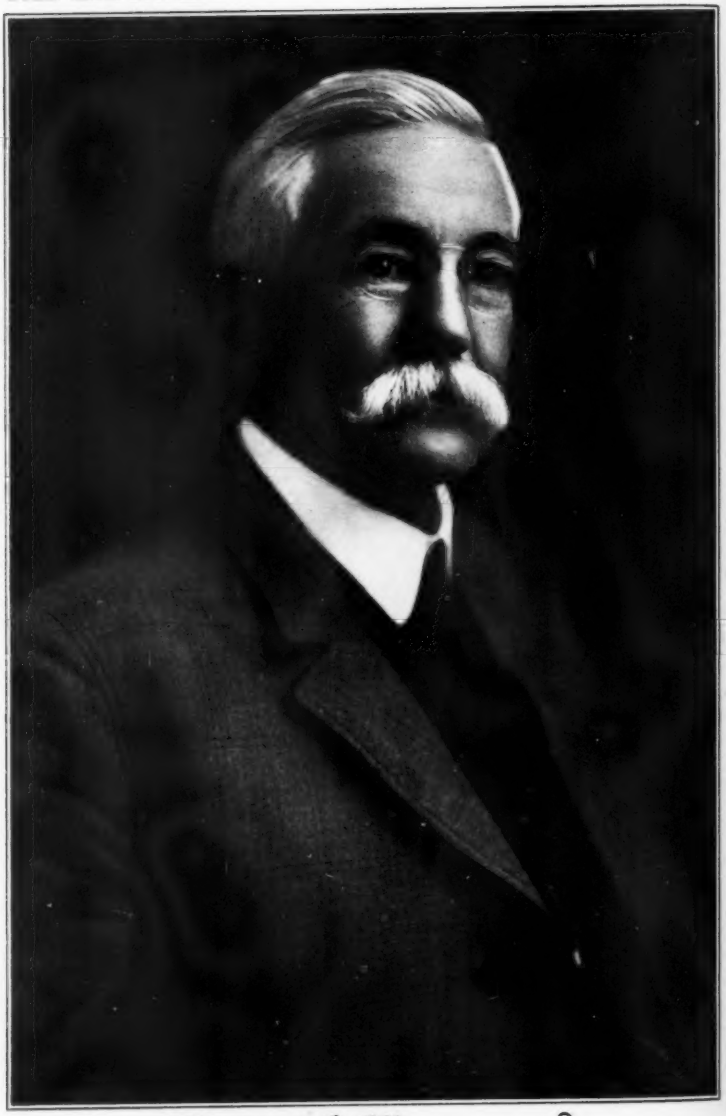

Robert S. Woodward

MEMORIAL OF ROBERT SIMPSON WOODWARD [1]

BY FRED. E. WRIGHT

Geology, like astronomy, covers a large field. To its study men of widely different training are attracted and find in it problems suited to their tastes and abilities. This diversity of interest is reflected in the membership of our Society, which includes not only field geologists, but also specialists from the biological sciences and from chemistry, mathematics, and physics. Dr. Woodward belonged to this last group of investigators, who are interested primarily in mathematical physics, but who, in the words of Dr. Woodward, realize that "the earth furnishes us with a most attractive store of real problems"; that "its shape, its size, its mass, its precession and rotation, its internal heat, its earthquakes and volcanoes, and its origin and destiny are to be classed with the leading questions for astronomical and mathematical research." To these problems men like Laplace, Fourier, Gauss, G. H. Darwin, and Lord Kelvin devoted much attention, and in so doing advanced both geology and their own mathematical physical sciences.

Dr. Woodward's contributions to geology were in the domain of geophysics, and, although his articles were printed many years ago, they still rank as the most important papers on these subjects thus far published in America. His influence, moreover, in stimulating and encouraging geological work and, in his later years, as president of the Carnegie Institution of Washington, in organizing and administering research projects in geophysics have been important factors in the progress of geology and of other sciences.

Robert Simpson Woodward was born on July 21, 1849, at Rochester, Michigan; he died on June 29, 1924, at Washington, D. C., at the age of seventy-five years, after a long period of illness and suffering, following an attack of influenza.

His early life was spent on a farm near Rochester, a village in Oakland County about 30 miles north of Detroit. His father, the Hon. Lysander Woodward, was one of the most progressive farmers in the State, who sought to apply scientific principles to the operation of his farm, and took a keen interest in public affairs. Farm land in this part of the State is of excellent quality and responds well to proper treatment. Without question, this attitude of mind of the father was passed on to the son, who ever afterward was an enthusiastic student of farming methods and in later years acquired and successfully operated, for recre-

[1] Manuscript received by the Secretary of the Society February 12, 1926.

ation, a farm in Montgomery County, Maryland, not far from Washington. The following biographical sketch of his father, given in C. R. Tuttle's General History of the State of Michigan, Detroit, 1873, pages 167-168, is significant:

"Lysander Woodward, one of the most prominent men in Oakland County, was born in the town of Columbia, Tolland County, Connecticut, November 19, 1817. His parents, Asahel Woodward and Harriet House, were natives of that State. In 1825, with his parents, he removed to the town of Chili, Monroe County, New York. From here he emigrated to Michigan in the fall of 1838. He married Miss Peninah A. Simpson on the 11th of May, 1843, and settled near the village of Rochester, Oakland County, Michigan, where he still resides. Mr. Woodward's chief occupation is that of a farmer, but he has held many important offices in his township. In 1860 he was elected representative from the first district of Oakland County to the State Legislature, and served with considerable distinction during one regular and two extra sessions. He was county treasurer of Oakland County two terms and performed his duties in a thoroughly satisfactory manner. Mr. Woodward was also president of the Oakland County Agricultural Society for three years, and in this position did great service in advancing the agricultural interests of the Detroit and Bay City Railroad and has been instrumental in canvassing for and promoting its construction. He was chosen the first president of this company in 1871, which important office he held up to May 15, 1873, and he still remains one of the directors of the company. Mr. Woodward owns one of the largest and best cultivated farms in Oakland County."

Doctor Woodward's mother belonged to the Simpson family—a name prominent in the annals of Connecticut. From his mother he inherited many genial traits of character and an interest in his fellow-man—traits that were an integral part of his personality.

His boyhood days were passed in an atmosphere of pioneer farm development, coupled with a broad interest in public affairs. His school training was excellent. The Rochester Academy which he attended ranked well among the schools of the State, and his teachers, especially one, were better than the average. On finishing the academy he wished to go to the university, but his father was not in sympathy with university training and was only persuaded to allow him to attend after most earnest appeals. Four years later, in 1872, the son graduated from the University of Michigan with the C. E. degree. Several summers during the college period were spent in field-work as aide on the United States Lake Survey. After graduation he became assistant engineer on the United States Lake Survey and retained this position for ten years, until 1882, when the work was practically finished.

During this period he was engaged chiefly in primary triangulation work on the Great Lakes, under the leadership of General Comstock, of

the Corps of Engineers, War Department. This gave him the most thorough training in primary triangulation, in latitude and longitude determinative work, in the testing of field instruments and field methods, and in the office adjustment of field observations by least-square methods. The results of this work were published in chapters 16 to 20 and 22 to 26 of General Comstock's Monographic Report on the Survey of the Lakes, Professional Paper No. 24 of the U. S. Army Engineers; also in several articles in technical journals. During this period Dr. Woodward acquired an interest in the earth as a whole—in its shape, its tides, its atmosphere, and in the host of geophysical problems, many of which still await solution. Throughout his life this keen interest was maintained and led him during the next decade to investigate some of the outstanding geophysical problems, and to solve them in spite of formidable mathematical difficulties. To him they had an irresistible fascination, and in later years he looked eagerly forward to the time when he could lay aside administrative duties and return to his research work in geophysics.

From the Lake Survey Dr. Woodward joined the United States Transit of Venus Commission as assistant astronomer, and was associated with it for two years, 1882 to 1884, with Professors Asaph Hall and William Harkness. During the transit of 1882 he was with the observing field party under Professor Hall at San Antonio, Texas. There were eight field parties, four in the United States and four in foreign countries, and each party took a number of photographs during the transit of Venus across the sun's disk. These photographs were deposited with the Naval Observatory, where they were carefully measured, and the data of measurement were used in computations to ascertain a more correct value of parallax than had hitherto been possible. An immense amount of labor was put into this task, but, as a result of improvements in methods along other lines, the parallax values thus obtained were superseded before the final report was completed and it was accordingly not issued.

The twelve years thus spent by Dr. Woodward in geodetic and astronomic work of the highest precision, but always with an immediate practical bearing, trained him to an engineer's sense of values and proportion. Whenever a problem arose he instinctively sought not only the means of solving it, but also the most direct method that would give results of the desired degree of accuracy with the least expenditure of energy. We shall now see how in the next decade he utilized this training to the utmost and made to geology and geodesy remarkable contributions that would otherwise have been impossible. This same resourceful attitude

of mind also makes for success in administrative work. It was inevitable, therefore, that in later years Dr. Woodward's balanced judgment should be sought on all sorts of technical and scientific problems, and that he should be drawn eventually into executive work.

From the Naval Observatory Dr. Woodward was called in 1884 to the United States Geological Survey as astronomer, where he soon became geographer, and then chief geographer in charge of the Division of Mathematics. The Geological Survey was at this time still young and had much to learn in all its branches; but its members were men—like Gilbert, Dutton, King, and Chamberlin—who, as masters in geology, with a virgin country to investigate, were full of enthusiasm and eager to accomplish much. It was a congenial atmosphere to enter, and during the next six years Dr. Woodward wrote his most important scientific papers.

His tasks on the Geological Survey were of two kinds, namely, those arising from the topographic branch in connection with field methods and map-work, and the investigation of problems of a geologic nature, but involving the behavior of the earth as a whole. To the first group of tasks Dr. Woodward had long been accustomed. They included latitude and longitude determinations at critical stations in different States, problems on map projection and the testing of field methods. He prepared a set of formulas and tables to facilitate the construction and use of maps. These tables, in amplified form, are still in use at the Geological Survey and constitute the basis for its topographic sheets. He prepared sets of instructions on methods best adapted for field use in primary and secondary triangulation. With the aid of several members of his division, he set up a small observatory for use in testing field instruments and in giving instruction to topographers in field topographic methods, especially latitude and longitude determinations. As a result of this work, the field methods were put on a practical engineering basis, thus securing the desired degree of accuracy with the minimum expenditure of funds and energy.

Geology at this time was moving forward rapidly, and the geologists of the Survey naturally turned to Dr. Woodward for assistance in problems of a mathematical physical nature. G. K. Gilbert found, for example, that within the area covered originally by Lake Bonneville the shoreline observed on an island in the central part of the lake was 129 feet higher than the strandline at its margin. The question arose, Was this difference in elevation due to the disappearance of the water? T. C. Chamberlin wished also to know to what extent the form and position of the sealevel may have been modified by the mere attraction of the

Pleistocene ice-cap. A general solution to these two problems was given by Dr. Woodward in Bulletin No. 48, on the "Form and position of sea-level, with special reference to its dependence on superficial masses symmetrically disposed about a normal to the earth's surface." This problem was one requiring for its solution mathematical work of the highest order and, in addition, the experience of the engineer, so to shape his formulas that they could be applied directly by the computer. The problem, as Dr. Woodward attacked it, became that of the deformation of the terrestrial geoid (as expressed by the surface of the sea) by the attraction of an ice-cap or other mass. It meant the investigation, by means of the potential theory, of the change in the equipotential surface of a large lake or sea as a result of the presence of an ice-cap, or of a body of water, or of a continental mass. The new set of formulas developed by this investigation sufficed to answer not only the questions of Gilbert and Chamberlin, but also other related questions concerning the distribution of density in the earth's mass and regarding the effect of continental masses on sealevel. In an historical note appended to this paper, Dr. Woodward analyzes the work of Croll, Archdeacon Pratt, D. D. Heath, and Sir William Thomson on this subject and shows the scope of each treatment. The work of these mathematicians demonstrated clearly the limitations that arise when the analyst is satisfied with a general solution to a problem and fails to obtain a solution that is suitable for computation purposes. On this point Dr. Woodward insisted repeatedly. Thus, in his papers on the free cooling and on the conditioned cooling of a homogeneous sphere, he "sought to express the solutions in such terms that the computer can, without undue labor, assign the temperature at any point within the sphere for any value of the time, having in mind always an application of the theory to the earth." Again, in his paper on the diffusion of heat in a homogeneous rectangular mass, he refers to the extraordinary studies of Fourier and Poisson and notes that "we must extend their work and adapt it to the practical needs of the computer."

Many problems were referred to Dr. Woodward while he remained with the Geological Survey. Thus Mr. Gilbert, in the course of his studies on the moon's face, wished to ascertain the average angle of incidence of meteors and moonlets impinging on the moon. Mr. Gilbert favored the meteor impact theory for the formation of the moon's craters and sought an explanation for the absence of elliptically shaped craters which one might expect to find if the meteors struck the moon at angles other than about normal to its surface. Dr. Woodward solved the general problem of the frequency of the different angles of incidence and showed how they varied with the assumptions made.

For the Division of Chemistry he studied the ratios of the weights of the chemical elements and made least-square adjustments involving the solution of 30 simultaneous equations.

From the geologist's viewpoint, Dr. Woodward's most important contributions of this period are his papers on the free and conditioned cooling of a homogeneous sphere and his application of the results presented therein to the secular cooling of the earth and to its age. Geological thought with respect to the age of the earth had been dominated for a generation by the conclusions of Lord Kelvin, who in 1862 and again in 1883 stated, after a detailed mathematical investigation of the subject, "We must allow very wide limits in such an estimate as I have attempted to make; but I think we may with much probability say that the consolidation can not have taken place less than 20,000,000 years ago, or we should have more underground heat than we actually have, nor more than 400,000,000 years ago, or we should not have so much as the least observed underground increment of temperature; that is to say, that Leibnitz's epoch of emergence of the *consistentior status* was probably between those dates." Geologists accepted this statement by Lord Kelvin because his arguments, so far as they could follow them, seemed sound. Nevertheless, although they could not refute his statements, they found it difficult to reconcile them with a mass of geological evidence. Dr. Woodward undertook to reexamine the entire problem, and carried the solution much farther than did Lord Kelvin or his predecessors.

The problem of a cooling sphere was not new.

> "It was very thoroughly discussed in its purely mathematical features by Fourier and Poisson, the pioneers in the theory of heat, and has been much studied by mathematicians of later date. Able and elaborate as their work is, however, it is not well adapted to the needs of practical application; it does not enable one to trace readily and accurately all the phenomena of cooling throughout their entire history. My investigations of this problem were necessarily made partly with a view to supplying the defect just named."

In his paper Dr. Woodward gives the data necessary for calculation of the secular cooling of the earth; the age of the earth derivable from such data; the distribution of the isogeotherms; the rate of increase of underground temperature and its variation with the time; the radial and volume contraction; the stratum of no strain.

He summarizes his conclusions in an address in 1889 as vice-president of the Section of Mathematics and Astronomy of the American Association. After presenting an excellent summary of the work of his predecessors, Dr. Woodward remarks that the conclusions of Lord Kelvin are very important if true.

"But what are the probabilities? Having been at some pains to look into this matter, I feel bound to state that, although the hypothesis appears to be the best which can be formulated at present, the odds are against its correctness. Its weak links are the unverified assumptions of an initial uniform temperature and a constant diffusivity. Very likely these are approximations, but of what order we can not decide. Furthermore, if we accept the hypothesis, the odds appear to be against the present attainment of trustworthy numerical results, since the data for calculations, obtained mostly from observations on continental areas, are far too meager to give satisfactory average values for the entire mass of the earth. In short, this phase of the case seems to stand where it did twenty years ago, when Huxley warned us that the perfection of our mathematical mill is no guaranty of the quality of the grist, adding that as the grandest mill will not extract wheat flour from peas-cods, so pages of formulæ will not get a definite result from loose data."

This statement by Dr. Woodward, together with his published retreatment of the entire problem, set the minds of geologists at rest concerning the restrictions imposed by Lord Kelvin. Some years later the generation of heat by transformations in radioactive substances within the earth's crust was discovered as a factor tending to retard the rate of cooling of the earth and to increase the limits set by Lord Kelvin.

In this same vice-presidential address Dr. Woodward summarized also the opinions regarding the contractional theory of the earth and the theory of isostasy which had been propounded only a few months before by Dutton, and he inferred "that isostasy is competent only on the supposition that it is kept in action by some other cause tending constantly to disturb the equilibrium which would otherwise result. Such a cause is found in secular contraction and it is not improbable that these two seemingly divergent theories are really supplementary." With reference to the solidity or the liquidity of the earth's interior he notes that "the difficulties appear to be due principally to our profound ignorance of the properties of matter subject to the joint action of great pressure and great heat. It is not clear how our knowledge is to be improved without resort to experiments of a scale in some degree comparable with the facts to be explained." Dr. Woodward was a firm believer in experiment. In his own words, "The price of progress, like that of liberty, is eternal vigilance. One must be ever active, ever patiently persistent, proving all things and holding fast to that which is good."

Dr. Woodward was also interested in the possible laws of arrangement of density in the earth's mass under the assumption that the density increases continually from the surface toward the center. Realizing its dependence on certain known properties of the earth, such as its mean density, its surface shape and surface density, and its constant of pre-

cession, he sought to determine the most probable law of increase, but found that the available data were not adequate for the purpose.

In 1890 Dr. Woodward resigned from the Geological Survey to accept a position on the United States Coast and Geodetic Survey. Major J. W. Powell, in his Report of the Director of the Geological Survey for 1889-1890, states that Dr. Woodward's "resignation was accepted with regret, as this Survey can ill afford to lose his rare ability for mathematical research. Since his first association with the Survey, in 1884, he has not only supervised the computations made in connection with the triangulation and astronomic determinations, conducted the computation of a series of tables for the use of the Topographic Branch, and given aid to geologists having occasion to read their data by mathematical methods, but he also made important additions to geologic science by discussing and advancing, on several lines, the theories of terrestrial physics. His discussion of the form and position of sealevel of the earth as dependent on superficial distribution of matter yielded formulas and numerical results of importance in the discussion of the physical results of the filling and emptying of the Bonneville Basin, of the formation and dissolution of the northern ice-sheet, and of all other phenomena involving the influence of superficial masses on the geoid. His discussion of the problem of a heated sphere, such as is presented by the earth, and of the contraction resulting from its slow cooling, is especially valuable for its indication of the additional work needed for the determination of the constants involved, and for the illustration of the dependence of the mathematical results upon important postulates, the possibility of whose future demonstration is not apparent. He has also studied and discussed the distribution of density and pressure within the earth and made a preliminary study of the stresses and strains involved in the deformation of the earth's crust within the limits of elasticity."

Dr. Woodward was called upon by the Coast and Geodetic Survey because of his long experience in precise triangulation "to devise means of testing in the most thorough way practicable the efficiency of the various forms of base apparatus used by the Survey, especially the efficiency of long steel tapes or wires." To this congenial task he applied himself with pleasure and enthusiasm. He devised the iced bar apparatus for measuring base lines and for calibrating steel tapes. His method for calibrating steel tapes was adopted by the Coast and Geodetic Survey and remains still the standard method. He was also the first to measure primary base lines with long steel tapes, and to prove that these tapes furnish the required degree of accuracy, namely, about one part in one

million. This work was of fundamental importance to geodesy and not only resulted in the saving of much money and time in field-work, but it placed the primary triangulation work of the Coast and Geodetic Survey on a higher plane than had been theretofore possible. He insisted, moreover, that, in the field, measurements of the kind and number only be taken to insure the desired degree of accuracy. His influence led Hayford some years later to revise and standardize the field and computational methods of the Coast and Geodetic Survey, thereby greatly increasing the speed of the work, lowering the costs, and placing the results on a uniformly high level of known precision. In this respect the Coast and Geodetic Survey set the example for other surveys the world over.

Maps constitute a very important item in geology, and for this contribution alone geology owes much to Dr. Woodward.

While at the Coast and Geodetic Survey Dr. Woodward prepared for the Smithsonian Institution the Smithsonian Geographical Tables. In the introductory part (93 pages) of this volume useful formulas are given for the geographer and cartographer, the geodesist and astronomer; also a brief statement of the theory of errors is included. The tables cover 180 pages and present data of interest to geographers and students of allied sciences. The third edition of these successful tables was issued in 1906 and was reprinted in 1918.

In 1893 Dr. Woodward was called to Columbia University as Professor of Mechanics and Mathematical Physics. From now on his work was that of the teacher and administrator. In 1895 he became dean of the College of Pure Science and was confronted with many problems that required tact and perseverance for their solution. His influence on the student body and on the students directly under him at Columbia was remarkable. He insisted on good work from each student, but he was ever ready to give help where it was needed. His thorough knowledge of mechanics and of the needs of the engineer enabled him to give to his engineering students the kind of information they most needed, and to train them to the attitude of mind essential to successful accomplishment in engineering work.

Intensely interested in the human element, and with a most attractive, genial, and lovable personality, his advice was sought on every side, both by the student body and by the faculty; so that, in spite of the best intentions and very hard work, he could not obtain for himself the desired periods of quiet to pursue his mathematical work, to which he looked ever forward.

He did, however, undertake, with the aid of Professor Wills and Dr. Deimel, an investigation into the possibilities of the double suspension

pendulum for the determination of the value of gravity. The advantage of this method over the ordinary method is the ease with which the length of the pendulum can be ascertained; its disadvantage is the uncertainty regarding the elastic behavior of the suspension fibers or ribbons. Dr. Woodward made a thorough mathematical investigation into the subject, but was called to another position before the experimental work had been completed, and he never again found an opportunity to finish the task. The records of the investigation, so far as they were carried, are on file in the Physics Department of Columbia University.

His interest was also aroused by A. L. Queneau in the cooling and crystallization of intrusive igneous masses as an example of a special case of the general theory of the cooling of a heated mass (bar or sphere), as developed by Woodward in 1888. Dr. A. C. Lane was the first to treat this problem, but his solution was somewhat different from that of Dr. Woodward. Queneau adopted Woodward's mode of treatment and applied it to a study of certain igneous rocks, arriving at essentially the conclusions reached by Dr. Lane.

In 1905 Dr. Woodward became president of the Carnegie Institution of Washington, and met the problems of this new kind of research institution with the same good common sense that characterized all his executive work. He analyzed each problem thoroughly, including that of personnel, and insisted that the institution be run on a thoroughly businesslike basis, that it live within its income, and that its money be spent with fair expectation of a good return. He established several departments of the institution and organized the institution about them. Miscellaneous appropriations to aid individual pieces of research were carefully scrutinized and every effort was made to spend the money entrusted to his care wisely and in the interests of science. Dr. Woodward showed keen appreciation of scientific activities outside his own sphere of astronomy and earth science and in his later years was much interested in archæology and in the humanities generally.

He believed that he who thinks clearly writes clearly. "It is so much easier to appear to write well, or even brilliantly, than it is to think clearly, that facile expression is often mistaken for sound thought." He himself wrote exceedingly well and coined many apt and telling phrases.

In his relations with the men of the institution under him he never failed to show the keenest interest and encouraged them wherever possible. His home life was of the ideal kind. Both he and Mrs. Woodward had a genius for hospitality and made each visitor feel at ease. Their home in Washington was ever the meeting place for scientific and other folk, just as it had been at Columbia University.

In the early days of the Carnegie Institution the effort to find and to aid the unusually talented man in his scientific work, as was the expressed wish of the founder, Mr. Carnegie, led to the placing of numerous small grants with men over the country who had special problems to solve. When Dr. Woodward became president he examined carefully into these random grants and found that a surprisingly small number yielded returns to science commensurate with the outlay. He therefore concluded that, so far as possible, the efforts of the Carnegie Institution should be concentrated on projects of large scope, which would probably not otherwise be attempted, and that these efforts for the most part should be carried forward by investigators in the employ of the institution. The result was greater emphasis on the departments of the Carnegie Institution, such as the Geophysical Laboratory and the Mount Wilson Observatory, and the more intensive development of all these departments. A few research associates who were able to give their entire time to special research problems were also maintained as integral members of the institution, but the voting of small grants to aid individuals connected with other institutions was minimized as a policy of the institution.

At the outbreak of the war Dr. Woodward was much disturbed by the trend of events in Europe, and when this country entered the war, he was influential in persuading the trustees to offer the services of the entire institution to the Government. The war work of the Carnegie Institution covered many fields of activity, from the manufacture of optical glass to military intelligence work, and to it all Dr. Woodward offered the most effective support. He himself was a member of the Naval Consulting Board, as one of the two representatives from the American Mathematical Society to the board.

Dr. Woodward was president of the Carnegie Institution from December 13, 1904, to January 1, 1921, a period of sixteen years. The first president of the institution, Dr. D. C. Gilman, president emeritus of Johns Hopkins University, had retired from active life, and he undertook the task only temporarily, until the best man for the position could be selected. When Dr. Woodward entered upon his duties the institution was two years old and had still to establish itself in the minds of the public and to determine on the best policies to follow. It needed at this critical period the mature judgment and experience that Dr. Woodward had acquired in governmental and educational positions; it needed also an enthusiastic and genial personality to carry through successfully the projects that merited encouragement and at the same time to avoid the far greater number of suggested projects which, although urged upon

the institution most insistently, really promised little return. On looking back over his years of activity, he states in his last report as president that "probably no other organization in the evolution of learning has been so beset by what Dr. Johnson called the anfractuosities of the human mind as the Carnegie Institution of Washington." But his keen sense of humor carried him over the rough places and his kindly, well-balanced attitude instilled in those with whom he came in contact the feeling of assurance that each proposal would be dealt with fairly and on its merits. Thus it was that the Carnegie Institution grew and flourished and contributed much to the development of geology and other sciences in this country.

Dr. Woodward received many honors from different scientific societies. He was vice-president of the Section of Mathematics and Astronomy of the American Association for the Advancement of Science, in 1889; its treasurer, 1894 to 1924, and its president in 1900; president of the American Mathematical Society, 1897 to 1899; of the New York Academy of Sciences, 1900-1902; of the Washington Academy of Sciences, 1915; of the Philosophical Society of Washington, 1910, and of the Literary Society of Washington, 1913-1914. He was a member of the National Academy of Sciences, the Astronomical Society, the American Physical Society, and fellow of the American Academy of Arts and Sciences and of the American Philosophical Society.

He was associate editor of *Science* from 1884 to 1924, and of the *Annals of Mathematics* from 1888 to 1889. Together with Prof. Mansfield Merriman, he edited a series of mathematical monographs; he himself contributed to the series the monograph on the "Theory of probabilities."

From the universities he received many honorary degrees: University of Michigan, Ph. D. in 1892; LL. D. in 1912; from University of Wisconsin, LL. D. in 1904; University of Pennsylvania, Sc. D. in 1905; Columbia, Sc. D. in 1905; Johns Hopkins, LL. D. in 1915. He was a member of the Century Club of New York and of the Cosmos Club in Washington.

In addition to his great attainments, Dr. Woodward possessed a simplicity and open friendliness of manner and character that endeared him to young and old alike. It was a privilege to know him, to feel his radiant enthusiasm, and to be uplifted by his hopeful outlook on this world and its many problems.

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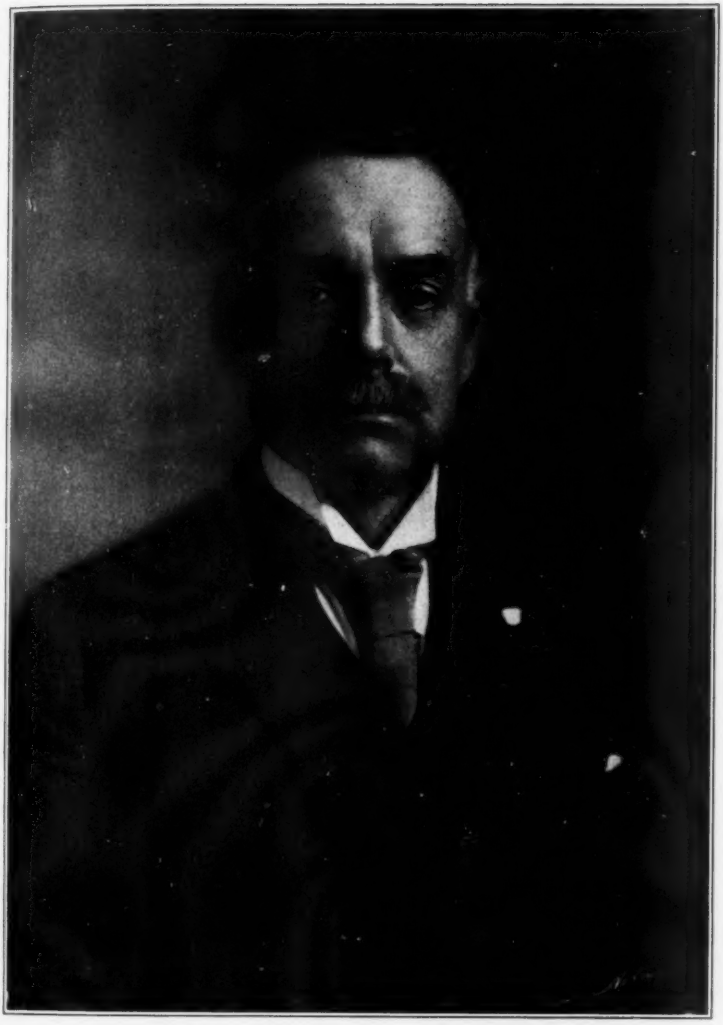
MEMORIAL OF JAY BACKUS WOODWORTH

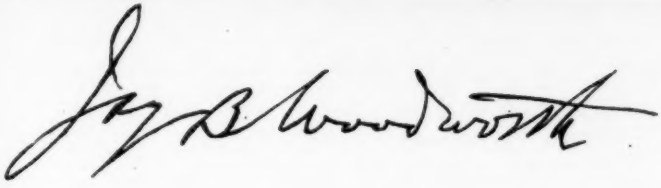
BY ARTHUR KEITH[1]

Jay Backus Woodworth was born January 2, 1865, in Newfield, New York. On September 21, 1891, he married Genevieve Downs, of Newark, New Jersey, and one daughter was born to this union. The early death of his wife, in 1911, was a heavy blow to him, and the mother's duties became his, as well as those of father. Woodworth was an only child, and neither of his parents had brothers or sisters; so that the line became nearly extinct with him. On August 4, 1925, he succumbed to a painful sickness which gradually sapped his strength, but not his courage. In an effort to regain his vigor he went to Florida during his sabbatical year. This brought to him what was undoubtedly a severe disappointment, in that after years of waiting for a chance to observe a severe earthquake on his own seismograph, the opportunity came—even twice—and he was away. He was cut off in the prime of his wisdom, and few will venture to try to fill the gap which he left.

Woodworth was the son of a clergyman, Rev. Allen Beach Woodworth, and from him no doubt came his strong, innate desire for truth. This desire and the willingness to be satisfied with nothing less was the key-

[1] Manuscript received by the Secretary of the Society February 15, 1926.





note of his life; with it went sincerity; yet Woodworth had none of the defects of too plain speaking. Few were the times when he criticized any one adversely, and he preferred to be silent rather than severe. Shams were his abomination, and no one had less patience with them than did Woodworth; but to those who tried, even though they fell short, Woodworth was kindly and encouraging and freely gave his help.

The love of nature, which is so commonly found in those with a passion for truth, was born in Woodworth, too. It was fostered by his parents and received the stimulus of outdoor life in many places among the hills of New York and New Jersey. In accord with the custom of those days, his father was transferred from time to time to new pastorates, so that Woodworth was educated in the grammar schools of various towns. He received his high school education in Newark, New Jersey, where his father was living at the time, and there his schooling seemed destined to end. He then made a short venture in business life, first as a secretary in the New York Life Insurance Company in New York; next he became an assistant manager in the Edison Illuminating Company of Boston. Apparently he was not satisfied with a career along this line, and soon, having definitely chosen a life in the service of science, he took up his higher education in the Lawrence Scientific School at Harvard. Here he came into contact with Shaler and from him received what slight impetus he may have needed to turn him definitely toward geology. Shaler's influence on him was strong, as on others, and Woodworth fast rounded into an able geologist. The spur of Shaler's ideas was of the utmost value. Under it Woodworth so grew and broadened that the young disciple later on was the peer or even the master of Shaler in some branches of his science. In 1894 Woodworth graduated with the degree of S. B. *cum laude*.

I first came in contact with Woodworth in his early years as a student in the Scientific School and as an instructor. Even then the marks of truth and sincerity as well as of kindly thoroughness were upon him. His career soon divided into two channels—that of the investigator and that of the teacher; if he had a choice, perhaps it was the former. Even if he had preferred that, however, nothing less than his best would ever have satisfied Woodworth in anything to which he put his hand.

In his early days at Harvard, beginning in 1890, Woodworth was closely identified with Shaler's geological work in eastern New England, and in a few years grew to be his coworker. The first considerable fruit of these labors, which were carried on under the auspices of the United States Geological Survey, was the report on the "Geology of the Narragansett Basin," published in 1899. This work was an accurate index to

Woodworth's mind, and the sound analysis and the breadth that he showed appeared in all of his later publications. This report, when it appeared, was the authority on that region; it still is so and it is likely to remain such for many years. In the same year the Geological Survey published the report by Shaler and Woodworth on "Geology of the Richmond Basin, Virginia." In this work, too, although on a smaller scale, the high grade of the Narragansett Basin work was continued; as far as the evidence warranted, his conclusions would go, but not a step beyond.

Shaler's strong interest in glacial geology was reflected in Woodworth's work and led him into numerous lines of investigation. One of these which turned out to be of superior importance was that on the "Ancient water levels of the Champlain and Hudson valleys." This was published by the New York State Museum and was of such commanding excellence that it was at once the authority on that topic and has so remained. The success of this work was such that it practically determined the emphasis laid upon glacial geology in Woodworth's later years, and it was the second milestone in his career.

Concurrently with his glacial work Woodworth carried on his investigation of the islands of Nantucket and Marthas Vineyard. He published several short articles concerning these islands, in which he showed important unconformities below the till and much deformation of the underlying Cretaceous beds by the ice. The discrimination of the history of these older beds was a great contribution to the geography and diastrophism of the northern end of the Atlantic Coastal Plain. On Cape Cod his similar studies culminated in a masterly analysis of the glacial deposits, both in detail and in broad outlines. His work on that district leads all others and without doubt will for many years be the standard. Only small portions have hitherto been published, but the full report now awaits publication by the United States Geological Survey, under whose auspices a large part of the work was done. This work will show a grasp of broad outlines and an ability to deal with details, which is a rare combination indeed.

In his later years Woodworth returned more and more to that side of geology which originally attracted him—the tectonic. In 1908 a seismograph was established at Harvard, at his request, and on his shoulders fell the task of operating it. It would seem that a geologist who already had the two major tasks of teaching and of investigation was sufficiently occupied, and I am sure that many of our Society know this to be the case. Woodworth carried them, however, and added thereto the burden of developing new methods and of watchful care over his instruments. The continuity of attention which this task requires is rarely realized,

but it is complete. Any instrument as delicate as a seismograph needs the most assiduous care, and no moment is free from possibility of an important record. Woodworth's success in improving methods of operation and the accuracy of his records soon brought him to the front in this line, and his communications and earthquake records were among those most prized. With them went the feeling that it was safe to tie to them and that there was no exaggeration of his specialty.

The subject of mountain-building was one of Woodworth's early concerns and always had an important place in his mind. Starting with his Narragansett Basin work, it continued in various little-noticed ways, and gradually there developed his theory of the normal sequence in mountain-building. This has never been printed in full; but it linked together as parts of a complete cycle, albeit far separataed in time, the upheaval of mountains by compression with folds and acid intrusions and the later tension and collapse of basins with normal faults and basic flows. This theory was laid before his students in the lecture room and was studied in the field during the excursions of his classes. A brief abstract of it was printed in the Geological Society of America Bulletin for 1920. His last publication on tectonic geology was his "Cross-section of the Appalachians in southern New England," published in 1923 by the Geological Society of America. Here again his anlysis of the problems was masterly, though brief, and his report presented generalizations and theories that were new and of great interest.

Entirely separate from this line of study was his expedition to Brazil under the Shaler Memorial Fund. This was the first use made of this fund, and it was fitting that Woodworth should have been the one to carry on for Shaler. This work furnished a determination of a period of glaciation near the close of the Paleozoic era. The difficulty of proving a matter of this sort is apparent to all and is particularly clear to any person who has attempted it. The value of each determination is great, not only on account of its rarity, but also for the light that it sheds upon the nature of climate and the movements of the earth.

It is clear from the foregoing matters in which Woodworth achieved success that he was far from being a specialist, with the limitations so often seen. This idea is strengthened by an examination of the list of his published articles, wherein is seen a very unusual breadth of interest.

In 1893 Woodworth was appointed instructor in geology at Harvard, assistant professor in 1901, and associate professor in 1912. His work as a teacher covered most of the field of geology; this was especially true in his courses for beginners. He was at his best with advanced students, and his lectures to them gave him more opportunity to draw upon

his extraordinary body of information. From this store he gave freely to all of his students, and much of it was made of things that are not to be found in the books. To those who tried he extended a helping hand, but those who were not sincere found Woodworth a different man. His own honesty and freedom from sham led him soon to detect insincerity, and he stood firm against it. He cared little for the applause of the immature, but the approval of those who understood was always dear to him. Students unnumbered have gone to him for help and obtained it, and those who could profit by a stimulus found it in plenty and were led far on their paths by Woodworth. He was familiarly known as "Woody," both among his friends and his students, and his influence has gone out in a great and widening ring.

During the World War Woodworth gave his best to the Reserve Officers' Training Corps and was a lieutenant in the corps. In the National Research Council during the period of the war his knowledge of seismology helped greatly in adapting the seismograph to the problems of warfare, especially the location of gunfire.

His other outside interests were numerous and some of them even extraordinary. His library on geologic subjects was large and excellent and showed a leaning toward the collection of early editions and of old reports and textbooks. This same leaning led him to form a collection of editions of Herodotus which was among the best in the world. The same high regard for the old carried him into genealogy, and he delved deeply into such matters concerning his own family.

His fund of humor was unusual, and few were the situations for which Woodworth did not have a story that was apropos. This keen sense of humor helped him to tide over some of his disappointments; he had them and a few were severe. He bore them without complaint, however, and only a few close friends ever knew how deeply they entered his heart. Old friends who returned to Cambridge or new ones who appeared were met by Woodworth with a hearty smile and a clasp of the hand. His hospitality was ready and genial and he was a good companion, but his nature led him to be receptive rather than to reach out for companionship.

Woodworth had nothing of the office-seeker in his make-up. If honors came to him, as they will to those of his ability, Woodworth accepted them simply and appreciated them. If they came not, that, too, was satisfactory, for he was a philosopher. His colleagues in science did him honor, not only by personal appreciation, but by the offices for which they selected him. He became a member of the Geological Society of America in 1895 and was in 1921 one of its vice-presidents. He was

president of the Seismological Society of America and vice-chairman of the American Geophysical Union, Section of Seismology. The American Association for the Advancement of Science included him among its members, as did also the American Academy of Arts and Sciences, the Washington Academy of Sciences, and the National Research Council. The Meteorological Society of America, the Boston Society of Natural History, and other societies held Woodworth in their ranks.

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SESSION FOR THE PRESENTATION OF SCIENTIFIC PAPERS

The session for the presentation of scientific papers was opened by an address of welcome by Dr. James R. Angell, President of Yale University, who referred to the long record of scientific achievement of Yale University, recalling the names of men who have been in the forefront of advancement in geologic science almost from its beginning in America—such men as Silliman, Dana, and Marsh, belonging to the pioneers of an earlier generation, who left a lasting impression on the science which has not lessened with the progress of time. Following them there has been a long line of successors who have maintained the ideals of their elders. Among them were the well-remembered names of Pirsson, Irving, Barrell, and Robinson, who have worthily maintained the traditions of Yale in the advancement of science.

TITLES AND ABSTRACTS OF PAPERS

RUBY MINES OF THE MOGOK DISTRICT IN BURMA

BY FRANK DAWSON ADAMS

(*Abstract*)

The geological succession in Burma, following the direction of the mountain ranges, strikes north and south.

The oldest member is a series of very highly metamorphosed pre-Cambrian rocks, which run throughout the entire length of the country and which present, where examined, about Mandalay and in the Mogok district, a striking resemblance to the Grenville Series in North America. An excellent section across this series is obtained along the road between Thabeikkyin, on the upper Irrawaddy River, and Mogok, which lies about 60 miles to the east, toward the border of the Shan States. In this section crystalline limestones are abundant, interstratified with pyroxene scapolite gneisses, etcetera. A nepheline rock (urtite) occurs with them near Mogok.

Rubies, sapphires, and many other precious stones are found in the limestones or in other rocks of the series. Being set free from their matrix by deep-seated subaerial decay, they are washed out of the residual and alluvial soils. Mogok has been the most renowned district in the world for the production of rubies ever since the dawn of history.

Brief remarks were made by Prof. Arthur S. Eakle, with reply by Doctor Adams.

FIRE AS AN AGENCY IN ROCK WEATHERING

BY ELIOT BLACKWELDER

(*Abstract*)

Among the various agencies that cause the disintegration and decay of rocks at the surface of the earth, fire deserves a more important place than is commonly accorded to it. Forest and brush fires annually ravage large areas, particularly in semi-arid regions, such as the Rocky Mountain province of the United States. By this means, over many thousands of square miles, boulders and outcrops have been fractured, thus causing more rock disintegration than all other processes combined.

The characteristic result of fire action on a block of rock is to cause fractures more or less parallel to the surface. Curved wedges and scales are thus broken off, leaving a progressively more rounded central mass. Such scales differ from those produced by chemical exfoliation, in that they are generally sound and undecayed.

It seems probable that the importance of fire has been overlooked, largely because its effects have generally been ascribed to diurnal changes of temperature. In another paper, however, the writer has shown that such small ranges of temperature are probably not the cause of such desquamation, and that the exfoliation generally ascribed to such changes is really due to hydra-

tion and other chemical alterations progressing inward along joints and outcrops.

Read by title in the absence of the author.

SUBMARINE DENUDATION

BY WALTER H. BUCHER

(*Abstract*)

Between more or less unfossiliferous shales and argillaceous limestones, fossil breccias recur at roughly comparable intervals in the Upper Ordovician series of the Cincinnati region. Specimens and slides were shown which, in the author's opinion, prove that, at least in their typical development, these fossil breccias represent what might be described as "concentrates." They consist of the coarser remains of organisms accumulated at the bottom when submarine erosion destroyed previously formed sediments, throwing the finer constituents into suspension. Many, if not most, of the unfossiliferous, fine-grained, cross-bedded limestone layers, which recur as frequently as the beds of "concentrates," must represent the finer material settled from suspension. They might be called "storm-drift beds." The record of these "concentrates" and "storm-drift beds" seems to point to major and minor variations in storm activity comparable to those familiar in Pleistocene and especially Postglacial time.

The most striking specimens indicate a partial subaqueous hardening or setting of the calcareous muds previous to reworking. It is believed that the formation of "wool-sack" forms, of contemporaneous folds, and of some intraformational breccias is the result of temporary submarine denudation attacking beds of different degrees of hardening.

Brief remarks were made by Dr. E. M. Kindle.

GEOLOGY OF SAINT HELENA ISLAND

BY REGINALD A. DALY

Read by title.

SANTA BARBARA EARTHQUAKE

BY ARTHUR L. DAY

(*Abstract*)

Four years ago the Carnegie Institution of Washington began a systematic study of California earth movements in which a number of other American agencies have cooperated. A very brief account was given of the progress of this investigation in providing an appropriate background for the study of such an earthquake as the recent one at Santa Barbara, in addition to the interpretation of the instrumental records. Lantern slide views of the physical destruction wrought by the earthquake in the city of Santa Barbara and vicinity will be shown, together with the efforts thus far made to locate the structural weaknesses in the region.

Brief remarks were made by Prof. A. C. Lane.

PLANS OF THE UNIVERSITY OF MICHIGAN EXPEDITION TO GREENLAND IN 1926-27

BY WILLIAM HERBERT HOBBS

(*Abstract*)

This expedition is to be undertaken in cooperation with the expedition of the Danish Government to Greenland in the same years, which expedition is to be led by the well-known explorer, Dr. Lauge Koch. The University of Michigan Expedition will make its base on the west coast, near Holstensborg, on Davis Strait, whereas the Koch Expedition will be based on Scoresby Sound, about two and a half degrees farther north and on the east coast. It is planned to run a line of traverse with transit and stadia from the fiord head near the Holstensborg base across the land ribbon and up over the inland ice surface for a distance of a hundred miles or more, in order to fix the position and the altitude of the meteorological stations which are to be established both on the inland ice and outside. The exterior stations are to be located quite near to the ice-margin, the main one at an altitude in excess of one thousand meters and the secondary station at a relative low level. Stations will be connected by radio and the main station will be provided with a long-distance instrument.

Studies of magnetic gravity and tides will also be carried out. Exploration of the upper air will be carried out by pilot balloons from the interior and from the main exterior station, and also by special seaplanes carrying meteorographs. It is hoped to continue all the meteorological stations for the period of one year, though most of the studies will have to be compressed within the four or five months of the available summer season. The Government bureaus are supporting the expedition and loaning for the scientific studies material or personnel or both. Of bureaus which are lending aid in this way there are the War Department and the Fisheries Bureau, the Weather Bureau, and the Coast and Geodetic Survey.

WORK OF SUBCOMMITTEE OF THE NATIONAL RESEARCH COUNCIL ON ESTIMATION OF GEOLOGIC AGE BY ATOMIC DISINTEGRATION

BY ALFRED C. LANE

The printed report of this subcommittee, under the title "Measurement of geological age by atomic disintegration," was distributed, and brief explanation of the working plans of the committee was given.

ERUPTION OF SANTORINI IN 1925

BY HENRY S. WASHINGTON

(*Abstract*)

The eruption began suddenly on August 11, between Nea Kaimeni and Mikra Kaimeni, and rapidly developed considerable activity, two lava flows filling the channel behind Mikra Kaimeni. The paper records the observations made by the author in September last. When he last saw it (September

19) the volcanic edifice consisted of a low dome, about 150 meters in diameter and about 25 meters high, composed of loosely aggregated large blocks. This was in very intense activity, the action being simultaneously of three distinct types, one of which was very unusual. There was much ejection of red-hot stones and ash. The lava resembles those of previous eruptions at Santorini, both in its mode of flow and in its mineral and chemical features. There was some evidence of submarine flow.

SOME RESULTS OF THE THIRD SEASON OF MONGOLIAN EXPLORATION BY THE THIRD ASIATIC EXPEDITION OF THE AMERICAN MUSEUM OF NATURAL HISTORY

BY ROY CHAPMAN ANDREWS AND CHARLES P. BERKEY

(Abstract)

The explorations of 1922 and 1923 resulted in locating several prolific fossil fields, and in gaining a working knowledge of the structural geology of the desert region of central Mongolia. The major stratigraphic elements were differentiated and defined. A beginning was made in interpreting the dynamic history and in learning how to use the differing physical habit of the country in guiding rapid reconnaissance. But there were many missing links in the story and many unsolved problems.

The season of 1925 gave opportunity to fill in some of these gaps and to study the most suggestive localities in greater detail. Route maps and geologic sections were made and several special localities were mapped in detail. Numerous evidences of cyclic change of climate were found. Many structural obscurities have been cleared up. Several new formations have been added, and the geologic column is much more nearly complete.

The most important locality studies were made (*a*) along the Altai Mountain range, where the latest orogenic movements took place and where Pleistocene history is recorded; (*b*) at Jisu Honguer, where a comparison between Paleozoic strata and the graywacke series could be made; (*c*) at Shara Murun, where additional Tertiary formational and structural detail could be worked out; and (*d*) at Shabarakh Usu, in the Djadokhta district, where Cretaceous strata continue to yield dinosaur remains and primitive mammals, where Paleocene strata are well developed, and where the bottom of a Pleistocene valley is clogged with Recent deposits carrying Old Stone-age culture of Man.

At this point, 1.15 p. m., the session adjourned for luncheon.

SESSION OF MONDAY AFTERNOON

The afternoon session was opened at 2 o'clock, in the Auditorium, with President Scott in the chair.

TITLES AND ABSTRACTS OF PAPERS

STRUCTURE OF THE CORTLANDT NORITE, NEW YORK

BY ROBERT BALK [1]

(Abstract)

Measurements of the primary structural features show that the intrusive has largely the shape of a funnel and is underlain by a highly folded and injected schist. A central zone of steeply dipping foliation separates two partial funnels, each of which contains a central core of a slightly older, basic and massive rock, which is underlain by foliated norite. These cores seem to represent early crystallized phases of the magma, caught up in the upward-moving residue. A later stage of magmatic differentiation is exhibited by mixed dikes with a kind of "pillow structure." In several places noritic dikes penetrate the country rock and have been subject to contemporaneous deformation of the schist. The ratio of elongation varies between 1: 1.1 and 1: 1.7.

Brief remarks were made by Prof. William B. Scott, with reply by the author.

SILICATE IMMISCIBILITY

BY J. W. GREIG [2]

(Abstract)

It has been found that mixtures of the oxides of many of the metals with silica in certain proportions form two immiscible liquids on melting. These mixtures have all a very high temperature of complete melting. Mixtures of other oxides, notably alumina and the alkalis, with silica show no such behavior. Immiscibility in some typical ternary systems of these oxides with silica has been studied. The bearing of these results on petrology was discussed.

PROBLEM OF THE NATURAL REDUCTION OF SULPHATES

BY EDSON S. BASTIN [3]

(Abstract)

The reduction of sulphates in sea water and in the waters of certain springs through the agency of living organisms, principally bacteria, has been well established by the researches of many observers. Within recent years geologic studies, principally in the United States, have disclosed evidence of the reduction of sulphates with concomitant development of hydrogen sulphide and of carbonates in the deeply buried waters of oil fields. This reduction has been attributed to certain components of the oil—that is, to *dead* organic

[1] Introduced by James F. Kemp.
[2] Introduced by N. L. Bowen.
[3] In collaboration with Frank E. Greer, C. A. Merritt, and Gail Moulton.

matter. Reduction of sulphates by *dead* organic matter at high temperatures is well established experimentally, but experiments by the writers, extending over many months, failed to yield any reductions at ordinary temperatures.

These results led the writers to search for *living* organisms in the waters associated with oil. Samples of mixtures of oil and water from constantly pumping wells in Illinois were collected, with the usual bacteriological precautions against contamination. The wells chosen were yielding waters low in sulphates and containing hydrogen sulphide gas. Cultures were made with mediæ containing sulphates and small amounts of iron salts, the latter serving as an indicator for hydrogen sulphide. In nearly all the cultures reduction of sulphates with development of hydrogen sulphide took place. In the solid mediæ abundant globular colonies of sulphate-reducing bacteria were obtained. It appears, therefore, that even if future studies should show that dead organic matter can reduce sulphates at ordinary temperatures, the possible action of living organisms must be taken into account, even in such situations as oil "sands" 500 to 1,500 feet below the surface.

Brief remarks were made by Messrs. K. C. Heald and J. L. Rich, with reply by the author.

CUMULATE PERIDOTITE DIKE

BY N. L. BOWEN

(Abstract)

A dike of peridotite occurring near the summit of Sgurr na Banachdich, in Skye, has a fine-grained, chilled selvage and sends a similar stringer into the adjacent olivine gabbro. Microscopic examination of these fine-grained facies shows that they are not peridotitic, as might be expected, but are ordinary fine-grained basalt or trap, nearly, if not quite, free from olivine. These facts suggest that the original liquid infilling of the dike was basaltic, and that the peridotitic composition of the main part of the dike was acquired later.

The dike proper exhibits a structure which may be called *cumulate* structure and which consists, as here exemplified, in the presence of 80 per cent or more of olivine, all of it in sensibly idiomorphic crystals exhibiting no granular, interlocking growths. Such a structure would appear to be impossible as a result of the growth of crystals from a liquid containing 80 per cent olivine, and it is believed that the crystals must have accumulated there from a liquid capable of precipitating only a relatively small amount of olivine. The original basaltic infilling of the dike, indicated by its chilled selvage, would appear to be the liquid concerned.

We have, then, in this dike strong indications of the formation of a peridotite dike by accumulation of olivine crystals from a non-peridotitic, presumably basaltic liquid.

LIQUID IMMISCIBILITY IN SILICATE MAGMAS

BY N. L. BOWEN

(*Abstract*)

With a recent paper by B. Asklund, on the "Granites and Associated Basic Rocks of the Stavsjö Area" as text, some of the facts that have recently been regarded as inimical to crystallization-differentiation in magmas were discussed and the failure of these facts to give the supposed support to liquid immiscibility were pointed out.

GRAPHS OF ROCK ANALYSES

BY ALFRED C. LANE

(*Abstract*)

Reviewing briefly various methods of representing rock analyses, such as Idding's kites, but especially the trilinear coordinates as used by Osann and Johannsen, it is shown that not merely three constituents and a residue can be represented by a line, as does the latter, but that one can indicate six, nine, or twelve constituents in the same way.

From the sides of the main triangle the three main constituents are laid off, giving an inner triangle; from the sides of this three other constituents, forming a smaller triangle within it. From the sides of this three more constituents may be laid off, if desired, making a third triangle.

The first inner triangle is located much according to Johannsen's convention, by a line from its vertex to its base, *but through the lower left corner of the next inner triangle*, not as placed by Johannsen. From this lower left-hand corner a line is drawn to the right side of the second triangle through the lower right corner of the third triangle. A third line from this lower right corner to the left side of the inner triangle fixes its position, and a fishhook figure of three straight lines determines nine constituents! A triangular dot would give three more. The question arises if there is a best standard arrangement.

MAGMATIC CARBONS AND HYDROCARBONS

BY J. VOLNEY LEWIS

(*Abstract*)

Methane, which is universally present in the igneous rocks, is considered as a possible source of magmatic hydrogen, water, carbon in its various elemental forms, carbon monoxide and dioxide, carbonates, and, under certain conditions, of other hydrocarbons.

Hydrogen, methane, and carbon monoxides are often found among igneous emanations and are "occluded" in all igneous rocks. Superficial sources can account for these substances only in part. Indeed, the more volatile of them are probably diffusing surfaceward in all parts of the earth, since rocks and minerals everywhere seem to have become charged with them. "The standard original gases of the lavas are the elements or compounds of hydrogen, carbon,

and nitrogen, in the order named, while chlorine and sulphur gases are to be regarded as accessory" (Chamberlin and Salisbury).

Magmas and their emanations are persistently deficient in oxygen, and both temperature and liquidity of rising lavas are augmented by the oxidation of combustible materials. It is pointed out that the amount of available oxygen varies greatly in different regions of the crust, and that under some conditions unoxidized residues may lodge in structural traps.

Briefly discussed are (1) synthesis of heavier hydrocarbons through the action of catalysts, and (2) the possible detection of evidence in some petroleums that might point to a magmatic source, in part or in whole.

Read by title in the absence of the author.

CRYSTALLINE ROCKS OF THE MIDDLE-SOUTHERN SAN GABRIEL MOUNTAINS, CALIFORNIA

BY WILLIAM J. MILLER

(*Abstract*)

With the exception of a paper by Arnold and Strong (1905), in which specimens of some of the rocks are described, very little has been published on the geology of the San Gabriel Mountains of southern California. During the last twelve months the writer has made a geological map of about 200 square miles of the middle-southern portion of the mountains. The purpose of this paper is to describe and interpret the various rock formations of the region surveyed.

The oldest rocks are to be classified among the diorites. The most typical and extensively developed of these may be called the Mount Wilson quartz diorite, so named because of the fine exposures on and near Mount Wilson. A hornblende-rich diorite, occurring in smaller masses, may be older than the Mount Wilson diorite or it may be only a facies of it.

A pinkish gray, more or loss foliated granite, which occupies a considerable area, is younger than the diorite.

Next in order of age comes a white to light gray, massive to moderately foliated granodiorite, which may be called the Mount Lowe granodiorite because of its typical occurrence on Mount Lowe and vicinity. It is extensively developed.

Mixed gneisses, consisting of diorite more or less intimately cut and injected by granite, are wonderfully developed in many facies and in large areas. They are cut irregularly by many pegmatite and aplite dikes.

A number of greenish gray dikes of quartz porphyrite sharply cut the Mount Lowe granodiorite and the mixed gneisses.

Latest of all are many small, sharply defined diabase dikes.

The paper concludes with a discussion of the age of the rocks.

VOLCANIC ASH DEPOSIT IN THE ORDOVICIAN OF VIRGINIA

BY WILBUR A. NELSON

(*Abstract*)

Two layers of volcanic ash in the form of bentonite were found in Rockbridge County, Virginia, in rocks of Ordovician age. This material is prob-

ably from the same volcano which produced the ash deposits described by the author in 1922 at the annual meeting of the Geological Society of America. The coarseness of the ash fragments and the fact that the layer is about 10 feet thick show that it is near the location of this ancient volcano and are added proof that this early Ordovician volcano was located under the Cumberland Mountains near the point where Kentucky, West Virginia, and Virginia meet.

Analyses of ash and other observations on this ancient volcano were given.

CONTACT ACTION OF PEGMATITE ON SCHIST

BY G. M. SCHWARTZ AND R. J. LEONARD

(*Abstract*)

The pegmatite of the Etta mine, in the Black Hills of South Dakota, is a stocklike mass of very coarse crystals of spodumene, feldspar, quartz, mica, and numerous rarer minerals. It is intruded into a complex series of pre-Cambrian schists which surround the Harney Peak batholith.

In a zone surrounding the pegmatite, and varying from 5 to 15 feet in width, the schistosity has been destroyed by contact metamorphism and a rock developed with a granoblastic texture.

The schists at a distance from the contact consist mainly of quartz, muscovite, and biotite, with a very few grains of feldspar, tourmaline, and apatite. The abundant phase of the contact rock contains a high percentage of feldspar and quartz, with about 5 per cent of muscovite and much more tourmaline, apatite, and zircon than is found in the schist. One local phase contains, in addition, large plates of biotite, and another is composed mainly of tourmaline, quartz, and apatite, with accessory tourmaline, magnetite, and zircon.

Chemical analyses show that the abundant contact phase, as compared with the schist farther out, has lost potash, magnesia, ferrous iron, and water and gained soda, lime, and phosphorus. Soda shows the most striking change, as it increases from 2 per cent in the schist to 7 per cent in the contact rock. The tourmaline rock shows no gain in soda, but contains high ferric iron; and, although boron was not determined, it may safely be assumed to have been increased to a marked extent.

Read by Prof. Frank F. Grout in the absence of the authors.

ORIGIN OF THE VOLCANOES OF MAUNA LOA AND KILAUEA

BY HAROLD T. STEARNS[1]

(*Abstract*)

Detailed geologic mapping of the District of Kau, which comprises about half of Mauna Loa and Kilauea volcanoes and over one-fourth of the Island of Hawaii, throws considerable light on the origin and development of Kilauea and Mauna Loa and the geologic history of the entire island. Three formations, consisting of ash and basalt, were differentiated: (1) the Ninole basalt, the oldest formation exposed in the district; (2) the Pahala basalt,

[1] Introduced by O. E. Meinzer.

which is separated from the Ninole by a great erosional unconformity and includes at the top a 55-foot bed of volcanic ash, and (3) the Kamehame basalt, which lies above the Pahala basalt. The Kamehame basalt was divided into two members on the map, namely, the prehistoric lava flows and the historic lava flows of Mauna Loa and Kilauea. Because no fossil evidence was found to correlate these formations with formations occurring on the mainland, the Ninole basalt is tentatively identified as Tertiary (?), the Pahala basalt as Pleistocene (?), and the Kamehame basalt as Recent and late Pleistocene (?). The sequence of events in Kau are briefly summarized as follows:

Tertiary (?) Time

(1) Building up of the Mauna Loa ridge above sealevel and the extrusion from a vent on this ridge of the lava beds in the Ninole formation. (2) Cessation of volcanic activity on the Loa ridge and the erosion of deep box canyons in the Ninole formation. (3) Beginning of faulting on the southeast side of the Loa ridge.

Pleistocene (?) Time

(4) Birth of Kilauea volcano at the intersection of the faults on the southeast side of the Loa ridge with the Kea rift. (5) Renewed activity from vents below 7,000 feet on the southwest slope of the Loa ridge. (6) Decline of faulting on southeast side of the Loa ridge as a result of the growth of Kilauea. (7) Birth of Mokuaweoweo vent on Loa ridge. (8) Extensive deposits of fine ash; maturity of Kilauea; almost complete cessation of faulting on southeast side of Loa ridge. (9) Active faulting on southern slope of Kilauea.

Recent and Late Pleistocene (?) Time

Prehistoric Time

(10) Passing from youth to maturity of Mokuaweoweo. (11) Increased activity on northeast rift (Puna ridge) of Kilauea.

Historic Time

(12) Mauna Kea dormant, Kilauea in old age, and Mokuaweoweo approaching old age with the beginning of a caldera. Faulting rapidly destroying the cone of Kilauea. (13) Lava flows from Kilauea and Mauna Loa and explosions at Kilauea.

Read by title in the absence of the author.

PETROLOGY OF A PORTION OF MALHEUR COUNTY, OREGON

BY B. COLEMAN RENICK[1]

(*Abstract*)

The geologic section along the lower Owyhee River, southeastern Malheur County, Oregon, was measured and studied in the field. The rocks consist of volcanic flows and dikes and sediments derived largely from rocks of volcanic origin. The oldest rocks are sediments consisting of conglomerate, arkosic

[1] Introduced by O. E. Meinzer.

sand, sandy shale, and tuff. These lie stratigraphically below what is believed to be the equivalent of the Columbia River basalt. Above these sediments in a portion of the region, and also below the Columbia River basalt, is a glassy rhyolite porphyry with quartz sparingly present. The Columbia River basalt is a normal basalt and the essential constituents are labradorite, hypersthene, and augite. Some beds of tuff are interbedded with the basalt.

Above the Columbia River basalt there are interbedded sediments and basalt flows. Both olivine and normal basalt are represented by these post-Columbia River flows, several of which show lithologic characteristics by which the local structure features may be worked out with considerable accuracy. The post-Columbia olivine basalt and some flows in the Columbia River basalt contain zeolites, and data are presented which suggest that they were erupted into water. The Payette formation and possibly also the Idaho formation are represented by these post-Columbia sediments, which consist of sand, sandy shale, ash, tuff, and fine conglomerate.

DEVONIAN VOLCANIC ROCKS IN THE VICINITY OF DALHOUSIE, NEW BRUNSWICK

BY W. V. HOWARD[1]

(*Abstract*)

In the valley of the Restigouche River and around the upper part of the Baie des Chaleurs, which form the boundary between the provinces of Quebec and New Brunswick, there are large areas underlain by sedimentary and volcanic rocks of Helderberg age. A section of this area lying between the towns of Dalhousie and Campbellton, New Brunswick, was examined by the writer, who found a great series of tuffs, agglomerates, and flows ranging in composition from dacite to basalt. Two volcanic necks were discovered, while the presence of a third is suspected.

The most abundant flows are of pyroxene andesite, which bear a very close resemblance to the rocks of Carmelo Bay, California, and also to some of the flows described by Calkins from the John Day Basin. They bear a general relation to some of the more basic rocks in the Aroostook area in Maine, but the similarity is not so great as to warrant the conclusion that the two areas form a single petrographical province, unless the Aroostook rocks represent a more highly differentiated series lying on the border of such a province.

There is, however, a remarkable similarity between the rocks of the Dalhousie area and the contemporaneous volcanic rocks of the Central Lowlands of Scotland.

The volcanic rocks of the Dalhousie area were deposited during a period of subsidence in the Dalhousie passage leading to the Appalachian Gulf. The greater amount of vulcanism in the Dalhousie passage than in the Saint Albans passage resulted in the earlier filling of the former, and in this area there is evidence of at least two periods, within Helderberg time, when at least a part of the passage became filled to above sealevel and was later submerged.

[1] Introduced by G. H. Chadwick.

ADDRESS OF THE RETIRING PRESIDENT OF THE MINERALOGICAL SOCIETY

At this time, 5.15 o'clock, arrangements had been made in the program for the address of Arthur S. Eakle, the retiring President of the Mineralogical Society of America, which was then given in general session. Title: Needed extension in mineralogic instruction.

With the conclusion of this address, the session closed at 5.45 o'clock.

Meetings of Monday Evening

PRESIDENTIAL ADDRESS

At 8 o'clock the presidential address of the retiring President, William B. Scott, was delivered before the combined societies in the Auditorium of Byers Memorial Hall. Title: Geological climates. The address is published in full in this number of the Bulletin.

ANNUAL SMOKER

At the conclusion of the presidential address, the members of the Geological Society of America and of the affiliated societies and their guests were invited to participate in a complimentary smoker given by the members of Yale University connected with geologic science. This was the first opportunity of the sessions to renew acquaintance and enjoy the social advantages of the meetings, and there was an unusually large attendance.

Session of Tuesday Morning, December 29

The morning session was called to order at 9.10 o'clock by President Scott, in the Auditorium of Sterling Chemistry Laboratory. The report of the Auditing Committee was presented, as follows:

REPORT OF THE AUDITING COMMITTEE

The undersigned have examined the accounts of the Treasurer for the year 1925 and find the same correct. We have checked the receipts and disbursements covered by appropriate vouchers and have compared the bank statement and find all details in accord with the Treasurer's statement as presented to the Society by the Council.

The securities in the Society's safe-deposit box will be checked by one of us and the results reported to the Secretary.

Respectfully,

PHILIP S. SMITH,
HARRY FIELDING REID,
WILLIS T. LEE,
The Auditing Committee.

This report was received and accepted, conditioned on receipt of an additional section of the report covering the securities.

Harry Fielding Reid was delegated to make an examination of the securities of the Society and submit a written report to the Secretary to complete the committee's duties.

REPORT ON SECURITIES

Securities owned by the Geological Society of America

2 Texas and Pacific Railway Company first mortgage 5 per cent bonds, numbers 11915, 20892, due June 1, 2000.
2 United States Steel Corporation second mortgage 5 per cent bonds, numbers 2964, 2974, due April 1, 1963.
2 Fairmont and Clarksburg Traction Company first mortgage 5 per cent bonds, numbers 29 and 30, due October 1, 1938.
2 Consolidation Coal Company first and refunding mortgage 40-year sinking fund gold 5 per cent bonds, numbers 11850, 11851, due December 1, 1950.
2 Southern Bell Telephone and Telegraph Company first mortgage 5 per cent bonds, numbers M13217, M13218, due January 1, 1941.
2 American Telegraph and Telephone Company 20-year sinking fund, 5½ gold debenture, numbers 63305, 63306, due in 1943.
3 Chicago Railways Company first mortgage 5 per cent gold bonds, numbers 20750, 20751, 45871, due February, 1927.
1 American Agricultural Chemical Company first mortgage 5 per cent convertible gold bond, number 6356, due October 1, 1928.
1 Louisville and Nashville Railroad Company 10-year 7 per cent gold note, number M3941, due May 15, 1930.
1 Commonwealth Edison first mortgage gold bond, number 49652, due in 1943.
2 Commonwealth Edison first collateral trust 5 per cent bonds, numbers 8562, 8563.
2 Anaconda Copper Mining Company first mortgage 6 per cent bonds, numbers M100571, M100572, due February, 1953.
2 Baltimore and Ohio Railroad first mortgage 5 per cent bonds, numbers M142100, M142101, due in 1948.
2 Central Railways Company of Baltimore consolidated 5 per cent bonds, numbers 547, 548, due May, 1932.
10 shares Iowa Apartment House Company stock.
40 shares Ontario Apartment House Company stock.

The above is a list of the securities in the safe-deposit box of the Society in Baltimore on February 19, 1926.

E. W. BERRY,
For Harry Fielding Reid.

The report of the Council, which had been laid on the table pending the approval of the Auditing Committee, was then formally adopted.

TITLES AND ABSTRACTS OF PAPERS

PRE-CAMBRIAN AND PALEOZOIC GEOLOGY OF FORTUNE BAY, NEWFOUNDLAND

BY NELSON C. DALE

(*Abstract*)

The outstanding physiographic features of the Fortune Bay area under investigation are the dissected plateau peneplain, the "tolt," or volcanic neck, monadnocks, and the glacially modified ria shoreline, the lineaments of which show occasional structural control.

For the most part the pre-Cambrian rocks of Fortune Bay are in the main represented by shales, dark reddish volcanic conglomerates and sandstones, varicolored metamorphic, pyroclastic rhyolites and basalts of Avalonian time, the more recent members of which show intrusions of pink granite porphyry.

The lower Paleozoic rocks, consisting largely of Lance and Middle Cambrian types, are in the main represented by fossiliferous shale and nodular limestones, sandstones, slates, and quartzites, which are found in fringelike remnants of a synclinorium.

The Newfoundland Cambrian fauna, a shallow-water fauna in large part, holding much in common with the Cambrian of Great Britain and North America, indicates that all fauna in the three countries belong to the same province, and that they migrated back and forth between North America and Great Britain by way of the shortest route through Newfoundland.

Read by title in the absence of the author.

RELATIONS OF THE GUADALUPIAN GROUP

BY N. H. DARTON AND J. B. REESIDE, JR.

(*Abstract*)

The formations of the Guadalupian group extending from northwestern Texas into southeastern New Mexico have been believed to be represented to the north by the Chupadera formation, but evidence was needed as to the stratigraphic relations and the conditions which have caused the marked faunal changes. In June, 1925, an examination was made of the Guadalupe Mountains and adjacent portions of the Pecos Valley which resulted in confirming the idea that, while the Delaware Mountain formation and part of the Capitan beds grade into the Chupadera formation, the upper part of the Capitan extends northeastward into red beds of the Pecos Valley, notably in

the oil field now being developed near Artesia. Large collections of fossils were made from the Delaware Mountain strata and the extension of the Capitan beds which show that the Guadalupian fauna changes greatly in character in its extension to the northward.

Brief remarks were made by Messrs. William B. Scott and John L. Rich.

CORRELATION OF THE METAMORPHIC ROCKS OF NORTHEASTERN CONNECTICUT WITH THOSE OF THE ADJACENT PORTIONS OF MASSACHUSETTS

BY WILBUR G. FOYE

(*Abstract*)

The metamorphic rocks of the Webster and Brookfield quadrangles of Massachusetts were mapped many years ago by B. K. Emerson and J. H. Perry. The geologic map of Massachusetts published in Bulletin 597 by Professor Emerson shows the results of this mapping. In 1906 H. E. Gregory and H. H. Robinson published a preliminary geologic map of Connecticut. The boundaries of the geologic formations do not correspond between the two maps and an endeavor has recently been made to establish the necessary corrections.

A map showing the new boundaries was exhibited and the age of the formations was discussed.

PROBLEM OF THE PLIOCENE IN THE PACIFIC COAST AND GREAT BASIN REGIONS

BY JOHN C. MERRIAM

(*Abstract*)

Pliocene deposits in the Pacific Coast and Great Basin region represent a total of more than 10,000 feet of strata. The history of sedimentation and erosion in this region is one offering exceptional opportunity for definition of conditions in Pliocene time.

The faunas of Pliocene deposits in the Pacific Coast region showing an exceptional number of stages with their time relations are clearly defined.

Understanding of Pliocene conditions as regards crustal movement, climatic change, and modification of life furnish the basis for origin of much that is critical in the Pleistocene and Recent. Concentration of study on the Pliocene will solve many of the questions touching later geological and paleontological stages which can be explained only with difficulty without full knowledge of Pliocene history.

STUDIES IN GEOLOGY AND PALEONTOLOGY OF THE TERMINAL PLEISTOCENE AND EARLY RECENT AND ITS BEARING ON THE STUDY OF EARLY MAN IN AMERICA

BY JOHN C. MERRIAM

(*Abstract*)

A discussion of the present situation relative to studies of the history of man in America. Consideration of exceptional opportunities for investigation of the history of Late Pleistocene and Early Recent deposits. A statement of needs and opportunities for furtherance of these researches.

Brief remarks were made by Prof. William B. Scott.

ORIGIN OF A KEWEENAWAN BOULDER CONGLOMERATE

BY E. S. MOORE

(*Abstract*)

Between Point Mamainse and Alona Bay, on the east coast of Lake Superior, there occur in several places large outcrops of a boulder conglomerate in the Middle Keweenawan series. This conglomerate contains granite boulders up to four feet in diameter, and it has been suggested by several geologists that it is of glacial origin. Bell claimed to have found striated boulders in it near Pointe aux Mines. A careful examination of the rock in the field during the past summer failed to disclose any definite glacial features, and the conclusion has been reached that the presence of the large boulders scattered through the formation is due to deposition near the base of large granite ridges. Thin-sections of the matrix show that it consists chiefly of fragments of volcanics, many of which are well rounded. The matrix does not resemble a boulder clay.

Brief remarks were made by Prof. A. C. Lane.

SUMMARY OF DISCOVERIES IN VERTEBRATE PALEONTOLOGY IN THREE SEASONS OF FIELD EXPLORATIONS IN MONGOLIA (1922, 1923, AND 1925)

BY HENRY FAIRFIELD OSBORN AND WILLIAM DILLER MATTHEW

(*Abstract*)

The new Cretaceous and Tertiary faunas discovered in Mongolia in 1922-3 have been further studied and preliminary descriptions published during the past year by Osborn, Cockerell, Matthew, Granger, Gregory, and Simpson. A part of the collection made in 1924 has been examined, but not yet published. The Cretaceous faunas, chiefly dinosaurs and primitive mammals, are extraordinarily fine material. Except for the Iren Dabasu fauna, they appear to represent peculiar facies not easy to correlate with the Cretaceous of America and Europe. This also is believed to be true of the Paleocene fauna. The Eocene faunas show marked affinities to the Upper Eocene of America. The Oligocene faunas appear to be more nearly related to those of Europe. The

character of the Cretaceous and early Tertiary faunas indicates an early initiation of progressive aridity.

Brief remarks were made by Messrs. William B. Scott and Charles P. Berkey.

JURASSIC FORMATIONS OF EASTERN UTAH[1]

BY JAMES GILLULY AND JOHN B. REESIDE, JR.

(*Abstract*)

The Colorado Plateau of eastern Utah is largely underlain by Triassic and Jurassic rocks. Detailed studies in San Rafael Swell and adjacent areas to the south and east have yielded much interesting information regarding the succession of deposits, their lateral changes, and the possible relations to the deposits of other areas. The Mesozoic section established includes eleven formations beneath the Dakota sandstone, several of which are new units.

At the base of the Mesozoic sequence is a marked unconformity, followed by the Lower Triassic Moenkopi formation. Unconformably above this is the Shinarump conglomerate (Upper? Triassic), followed with probable conformity by the Upper Triassic Chinle formation. No Middle Triassic has been definitely recognized.

The rocks with which this paper chiefly deals lie unconformably on the Chinle. At the base is a widespread group of thick sandstones—the massive Wingate sandstone, partly water-laid, partly æolian, usually red—followed conformably by thin-bedded, water-laid sandstone and minor shale with more or less red coloring, the Todilto formation; and this in turn by the massive, usually white, Navajo sandstone, in part water-laid, but probably in large part æolian. The Todilto formation is probably fluviatile, though it may be marine, while the Wingate and Navajo sandstones are probably nonmarine. This group has never yielded determinable fossils, but because of the unconformable relation to the Upper Triassic Chinle formation it is provisionally assigned to the Jurassic.

The sandstone group is succeeded, possibly unconformably, by a group of marine Jurassic beds equivalent to the Sundance formation of Wyoming and here divisible into four formations:

(1) At the base a formation of limestone, gypsum, sandstone, and gypsiferous shale containing a marine fauna.

(2) A silty, red, well-bedded sandstone series, with some minor red shales, changing eastward into a massive, light-colored, partly æolian sandstone.

(3) Resting with small angular discordance and marked erosion on the preceding beds, a glauconitic grit and sandstone containing marine fossils and changing eastward and southward into gypseous shales and thin shaly sandstones.

(4) Widespread, evenly bedded red sandstones and thin shales with siliceous crusts.

Upon the Jurassic beds enumerated, rest with marked unconformity conglomerates, sandstones, and shales of continental origin and containing dino

[1] Published by permission of the Director of the U. S. Geological Survey.

saur remains at many localities, hitherto constituting the upper part of the McElmo formation, but in this paper, on lithologic and paleontologic grounds, referred to the Morrison formation. It includes the Salt Wash sandstone member at the base and is assigned with doubt to the Cretaceous. Upon the Morrison formation lie, also with marked unconformity, the conglomerate and sandstone, with minor shale and coal, of the Dakota formation, and upon it the marine Mancos shale.

Brief remarks were made by Dr. Whitman Cross, with reply by Mr. Gilluly.

BURIED PENNSYLVANIAN CHANNELS AND SAND BARS OF EASTERN KANSAS

BY JOHN L. RICH

(*Abstract*)

Drilling for oil and gas in eastern and east central Kansas has revealed the presence in the Pennsylvanian shales of a number of long, narrow sand bodies which commonly serve as oil or gas reservoirs. On many of these sufficient drilling has been done to outline closely the form and shape of the sand bodies. Two principal types are found: The one filling distinct channels cut into the adjacent shales, the other having the characteristic features of barrier sand beaches and bars, such as are found along much of the Atlantic and Gulf coasts of the United States. The paper discusses characteristic features of these sand bodies; their probable origin; their paleographic significance; and the possible application of physiographic principles to the finding of their extensions.

Brief remarks were made by Prof. W. H. Twenhofel, with reply by the author.

SILURIAN ROCKS OF ILLINOIS

BY T. E. SAVAGE

(*Abstract*)

Silurian rocks in Illinois occur in four separated areas. In the extreme southwest part of the State, in Alexander County, Edgewood, and Sexton Creek (Brassfield), formations are well developed. In the west-central part, in Jersey and Calhoun counties, north of the "Cap au Gres" fault, the same formations are exposed and also several feet of higher Silurian strata corresponding to the lower part of the Joliet formation farther north. In northern Illinois the Silurian rocks outcrop in the northeast and the northwest parts of the State. In both of these areas about the same succession of Silurian strata is exposed. The strata in these two areas were probably once connected, but have since been separated by the erosion that leveled off the crest of the La Salle anticline, which was not an effective barrier to the spread of the interior sea during the greater part of Silurian time. In these northern areas not only Alexandrian strata are present, representing Edgewood and Brassfield time, but also Niagaran rocks corresponding in age to some part of the Lockport and Guelph divisions of the east.

In this paper the Silurian formations of the State are described and correlated with rocks of this system in other parts of the continent.

UPPER CRETACEOUS SHORELINE IN UTAH

BY EDMUND M. SPIEKER AND JOHN B. REESIDE, JR.

(Abstract)

Data collected in recent field seasons on the western margin of the Wasatch Plateau, between Manti and Salina, Utah, serve to correlate satisfactorily data gathered by various earlier students in southwestern Utah and in northern Utah and southwestern Wyoming and make possible an interpretation of the sequence of stratigraphic events in the whole region. Comparison of the central Utah section with those of the other regions mentioned shows several striking points of similarity which demonstrate parallelism of conditions on and near the shore of the Cretaceous Sea along the line adjoining the localities compared. On the other hand, comparison of the Manti-Salina sections with that of the east front of the Wasatch Plateau shows striking differences, and rather sharply defines the zone of critical shoreward change in the sediments of the region.

Sedimentation in Upper Cretaceous time began with coarse materials, locally associated with coal beds and containing in the later part some beds with brackish water and others with marine fossils, apparently near-shore deposits. These fossils are of lower Colorado (lower Benton) age. Then the shoreline moved westward and marine muds were laid down on the earlier coarse materials. These are of middle Colorado (upper Benton) age. Then the shoreline moved eastward again, and coarse materials with both brackish water and marine fossils were deposited, again near-shore sediments. These are of upper Colorado (Niobrara) age. The succeeding beds are nonmarine in the area treated and may contain one or more interruptions corresponding in time to the continental sedimentation taking place farther to the east and now represented by much of the Mesaverde formation. The highest beds of the Cretaceous sequence have yielded nonmarine fossils much like those of the latest Cretaceous of other areas. Apparently in Montana time the shoreline was east of the area here considered.

FOSSIL RHIZOPODS OF THE GREEN RIVER OIL SHALE

BY W. H. BRADLEY [1]

(Abstract)

Finely preserved representatives of three genera of Rhizopods have been found associated with the micro-flora of the oil shale in the Green River formation of Colorado and Utah. This paper describes three new species and discusses briefly their rôle in the origin of the oil shale.

[1] Introduced by J. D. Sears.

PRE-CAMBRIAN SEDIMENTATION IN NORTHERN COLORADO

BY MARGARET BRADLEY FULLER[1]

(*Abstract*)

Field study of the Front Range, in northern Colorado, reveals the presence of much schist and gneiss derived from sediments by contact and regional metamorphism against great stocks and bathyliths of granite. Similar conditions hold for the Park Range from Rabbit Ear Pass northward.

There is a distinct sequence of metamorphic zones on the eastern and western flanks of the Front Range which are related to three factors: 1, the compound character of the central axis of granite intrusives; 2, the original gradation and character of the sedimentary rocks from which the schist and gneiss were derived; 3, the great depth at which metamorphism took place. Distinct zones are not apparent in the schist of the Park Range, although it was derived from association with several great batnyliths of granite.

Under the microscope the schist of the eastern flank of the Front Range lacks hornblende, which mineral is present in subordinate amounts in the schist and gneiss of the western flank. Hornblende forms one of the chief minerals of the metamorphic rocks of the Park Range area, but biotite is rare. Other mineralogic features may be traced from east to west across the pre-Cambrian areas of northern Colorado. Further studies are contemplated, which will, it is hoped, furnish light on the conditions of sedimentation and the relations of land and sea during the pre-Cambrian over much of northern Colorado.

Certain conclusions have been reached in the present study: 1. The sedimentary rocks deposited in the pre-Cambrian seas were very thick. 2. The rocks at the east were fine grained and highly siliceous in content. Beds of conglomerate and limestone were thin and infrequent. The siliceous beds graded westward into thin-bedded clays and shales. Locally, as in the Park Range area, the shales were interbedded with fine-grained conglomerates and infrequent basic lava sheets, flows, and tuffs.

Read in full from manuscript.

Brief remarks were made by Prof. James F. Kemp.

GROUND WATER PROBLEMS ON THE BARRIER BEACHES OF NEW JERSEY

BY DAVID G. THOMPSON[2]

(*Abstract*)

The water supply for Atlantic City and neighboring resorts situated on barrier beaches is obtained largely from a Miocene sand bed below 300 feet of clay which effectively shuts out the salt water in the overlying horizons. Both are part of the Kirkwood formation, which outcrops some 45 miles to the northwest. The water-bearing sand is penetrated at Atlantic City at about 800 feet, but its depth increases southward, and at Wildwood, about 35

[1] Introduced by R. T. Chamberlin.

[2] Introduced by Kirk Bryan.

miles distant, it lies about 100 feet deeper. During the past 30 years, as a result of heavy pumping, the static head of water in the sand has dropped more than 80 feet, and the effect of further increases in pumping is a matter of concern.

An automatic gage on a well shows semidiurnal fluctuations in head that are obviously due to the tide. The daily range varies from about 1.5 to 3.0 feet, or a little more than 50 per cent of the tide range, and it changes from spring to neap tide. When the tidal fluctuations are eliminated, a major periodic fluctuation is found that is due to fluctuations in pumpage: when the pumping increases in summer, the head declines, and when it decreases in winter, the head rises. From this it is concluded that the head will drop still further as the draft becomes greater, and that one factor determining the ultimate yield of the Atlantic City sand will be the limit of economic pumping lift.

A factor that may prove equally as important is the danger of drawing salt water into the wells from the ocean. This leads to speculation as to conditions off-shore. The data at hand suggest that the Atlantic City sand has an outlet beneath the ocean, that salt water pervades it within a few miles of the shore, and that there is a real danger of the formation along the coast being badly contaminated by salt water if the pumpage is too heavy.

CONTRIBUTION TO SEDIMENTATION

BY E. M. KINDLE

The contribution offered by Doctor Kindle took the form of lantern exhibits of shore processes, using the moving-picture method.

At this point, 1.10 o'clock, the session was adjourned for luncheon.

DEDICATION OF PEABODY MUSEUM OF NATURAL HISTORY

The regular program of the Society was discontinued for the afternoon, so that all of the societies could join in the dedication of the Peabody Museum. Opportunity was given to inspect the remarkably fine display of geologic and paleontologic exhibits. The dedication ceremony was attended by a very large gathering. Dr. James R. Angell, President of Yale University, presided, and the following addresses were given:

The rise of natural history museums in the United States, by Prof. Charles Schuchert.

The origin of species, by Prof. Henry Fairfield Osborn.

After the presentation of these addresses, Prof. R. S. Lull outlined the plan of the museum and invited those in attendance to inspect the exhibits.

ANNUAL DINNER

At 7 o'clock the Geological Society and its visitors and guests, together with the members of the Paleontological Society, the Mineralog-

ical Society of America, and the Society of Economic Geologists, assembled in the dining room of Memorial Hall for the annual dinner. There was an attendance of 318, and the appointments proved to be excellent for the purpose. At the conclusion of the dinner, President Scott, acting as toastmaster, presented the following speakers: Herbert E. Gregory, Alfred C. Lane, Frank D. Adams, John C. Merriam, E. L. De Golyer, Kirtley F. Mather, and James F. Kemp.

Session of Wednesday Morning, December 30

The regular session of Wednesday morning was called to order at 9.10, with President Scott in the chair.

TITLES AND ABSTRACTS OF PAPERS

HYPOTHESIS OF MOUNTAIN BUILDING

BY E. C. ANDREWS

(*Abstract*)

1. The general shape of the earth is an approximation to a spheroid of revolution, with land surfaces occupying about one-quarter of its area, nevertheless averaging less than half a mile in height above sealevel, and with a continuous water surface occupying the remainder. Notwithstanding the great area of the ocean, its depth is only about one-fifteen-hundredth of the length of the earth's radius.

The Archean rocks of the continents are arranged so that their upper portions dip from the nuclei and outlying zones in which they occur toward the oceans and toward the continental centers, with a general tendency oceanward after due allowance has been made for the undulatory appearance of the major landmasses. The continents themselves have their margins raised in the form of plateaus near the oceans and within the Tethys of Suess.

The trend of mountains is generally parallel to continental and insular margins or to the longer axis of Tethys. All mountain ranges, moreover, are in the form of plateaus with folded and warped margins, and all have the appearance of earth waves whose main movements are vertical, but which have a lateral component, especially at relatively shallow depths from the surface.

The general shape of the earth's surface suggests that the outer portion of the crust is in a state of equilibrium under the influence of gravity, of a tendency to "rock flowage," and of earth rotation, and it suggests that this more superficial portion rests upon material which is solid during individual, but very small, divisions of time, but which is undergoing gradual deformation without marked rupture, except at certain very restricted and shallow zones. This interaction produces earth waves which are mutually supporting, but which are changing in form and position with extreme slowness.

2. In the earth's crust there are:

a. The weight of the component rocks and minerals.

b. The tendency of rocks to suffer deformation, without rupture, under the action of their own weight.

c. The tendency of the whole continuous crust to give lateral support to its various portions, and thus to prevent "rock flowage."

d. The "bond," or interlocking strength, of the rock units of the earth, which tends also to prevent "rock flowage."

e. The rotation of the earth on its axis.

f. The zone of slight or negligible pressure at the earth's surface (approximately one atmosphere).

The interaction of these variables is such as to produce a bulging of the equator and a set of earth waves or undulations at locations of relative weakness of bond, as compared with tendency to "rock flowage." The earth waves are mutually supporting; nevertheless, they are unstable structures if the unit of time considered be very large. The heights of mountains are a compromise between the force of gravity, the tendency to "rock flowage," and the strength of the structures of the overlying crust. The greater the radius of the globe, other things being equal, the less pronounced are the earth waves or mountain ranges and associated "deeps." This action is most marked near the surface only, owing to the increasing factor of lateral support with a decrease of volume of successive shells with progressive approach to the earth's center.

Read by title in the absence of the author.

LATE TERTIARY AND PLEISTOCENE FAULTING IN WESTERN NEVADA

BY HENRY G. FERGUSON

(Abstract)

Study of the Hawthorne and Tonopah quadrangles, Nevada, shows that the major faults of Miocene and later age follow definite systems. This arrangement may be due to control by structural elements of pre-Tertiary origin.

Some of the faults have not been active since Miocene time; on others there has been no movement since the Pliocene.

Pleistocene faults have given direct topographic expression to several of the ranges, but on many of these there has been no movement since the early part of that period. The ranges that have fresh scarps also show evidence of early Pleistocene movement, and in some cases of still earlier movement along the same fault.

PROGRESS IN THE SURVEY OF THE IVANPAH QUADRANGLE, NEVADA-CALIFORNIA

BY D. F. HEWETT

(Abstract)

Work in the northern half of the quadrangle (1,800 square miles) shows that 23 areal units may be mapped. These range from pre-Algonkian gneissic

granite through a thick Paleozoic and early Mesozoic section to Tertiary intrusives and extrusives. The most interesting stratigraphic feature is the increase in the thickness of the pre-Devonian units from 3,000 feet on the east side to 12,000 feet on the west side of the quadrangle, by the gradual thickening of each of the three lowest units (Cambrian).

The deformation of the region includes folding, thrust and normal faulting, probably in early Tertiary time, as well as later faulting. In the eastern half of the quadrangle, there was widespread erosion as deep as the gneisses before the deposition of mid-Tertiary tuffs and flows. The present outstanding physiographic units are marked out by late Tertiary normal faults, most of which were localized along old breaks, some as old as pre-Algonkian. The criteria used in the determination of the ages of the faults are presented.

STRUCTURAL STUDIES IN SOUTHERN NEVADA AND WESTERN ARIZONA

BY CHESTER R. LONGWELL

(Abstract)

Examination of eleven ranges west of the Grand Wash Cliffs has revealed complex regional structure. The earliest deformation of the sedimentary rocks is characterized by great thrust-faults dipping westward. Some of these thrusts have vertical displacement of 10,000 to 14,000 feet and one has horizontal displacement of at least 18 miles. The Muddy Mountain thrust-zone has been traced to the north along the east front of the Mormon Range for a total distance along the strike exceeding 60 miles. Farther west the combined thrust-zones of the Las Vegas, Sheep, and Spring Mountain ranges can be traced about 100 miles along the strike. There is definite evidence that two of the larger thrust-plates were pushed forward over erosion surfaces.

Following the thrusting movement, there was normal faulting on a large scale. The prevailing trend of the normal faults is generally north-south, but important sets strike north of east and others northwest. The combined effect of these faults has been to break the crust into a mosaic of blocks. Much of the faulting occurred during the late Tertiary, and there has also been considerable post-Tertiary movement. The area affected by intense normal faulting reaches only a few miles east of the most easterly visible thrust and terminates abruptly at the Grand Wash fault, which parallels closely the strike of the larger thrusts. This relationship suggests that the normal faulting was in some way conditioned by the earlier thrusting.

Attempts to trace the thrusts farther north are made difficult by the broken character of the basin ranges and by a wide belt of late Tertiary volcanics. However, the suggestion is strong that the southern Nevada thrusts are in a continuation of the great belt of early Tertiary deformation, including the Willard, Bannock, and other major thrusts of the northern Rockies.

At the conclusion of this paper, discussion of it and of the two preceding papers was participated in by Messrs. A. C. Lawson, L. G. Westgate, J. L. Rich, and C. R. Longwell.

DYNAMICS OF FAULTING

BY HARRY FIELDING REID

(*Abstract*)

It is found that merely horizontal tensions or compressions will not account for the characteristics of faults. It is necessary to consider vertical forces also. When this is done, we find a relation between the horizontal and vertical forces on the one hand and the dip of the fault on the other. It is found that horizontal pressure is necessary to produce a normal fault with steep dip. As the pressure increases, the dip becomes steeper, passes the vertical, and a reverse fault is produced. Reasons are given for believing that there is a strong horizontal compression everywhere at a short distance below the earth's surface, and that this may have a marked influence on the steepness of most normal faults.

Brief remarks were made by Prof. W. H. Bucher.

POST-CRETACEOUS OROGENY IN CENTRAL UTAH

BY EDMUND M. SPIEKER

(*Abstract*)

By far most of the territory now covered by the Colorado plateau was inactive during the great series of orogenic movements which built up the Rocky Mountains. Much of the area of the High Plateaus, however, west of the eastern tier of the group underwent considerable compressional deformation during the interval between late Montana and early Eocene time. The eastern margin of this late or post-Cretaceous folding extends northeastward from southwestern Utah to the Manti region, where it turns abruptly northward, passing west of the northern half of the Wasatch Plateau and east of Thistle, toward the region east of Coalville. The mountains thrown up in this folding were greatly eroded, the resulting sediments were spread eastward, and on the eroded surface were deposited continental sediments of Eocene age. The vast amount of erosion which took place during this interval is worthy of serious note. Furthermore, the close proximity of the pronounced nonconformity at the western edge of the Wasatch Plateau to the eastern face of the plateau and the Book Cliffs argues strongly for a considerable disconformity there, where a significant stratigraphic break is in general difficult to find.

The great uplift of late Tertiary time brought the whole mass to its present elevations, and toward the close of this uplift normal faults and homologous monoclinal folds were produced by tensional and gravitative stresses possibly related in origin to the vast outpourings of lava which took place in the High Plateau at about this time. At least two periods of normal faulting are discernible. Several striking exhibitions of both older and younger structures, and of the superposition of younger on older, are visible in the belt fronting the Wasatch Plateau between Manti and Sterling.

Brief remarks were made by Messrs. W. T. Thom, Jr., D. F. Hewett, H. G. Ferguson, and F. J. Pack.

TIDAL FORCES IN THE MAKING OF CONTINENTS AND MOUNTAINS

BY FRANK BURSLEY TAYLOR

(*Abstract*)

1. Brief review of geological evidences which show, without regard to source or nature of cause, that there was a well-defined and strongly marked increase in mountain-making during and since the Tertiary Age.

2. Review of evidences showing that the Tertiary mountain ranges were caused by horizontal sliding of continental crust-sheets moving on a potentially viscous basal layer made actively viscous by added horizontal stress. Analysis shows that northern continents moved in southerly directions, southern continents in northerly directions. The equatorial plane divides complementary halves.

3. Evidences showing nature of cause of horizontal crust-sheet movements: Distribution of continents and Tertiary mountain belt in latitude and hemispheres, coupled with the direction of the movements, is decisive as to the nature of the cause, showing it to be external, not internal; hence all supposed contractional and other internal causes are excluded. Tidal force is the only cause available.

4. Diagrams are presented showing preliminary analysis of manner of movement of crust-sheets, and action of tidal forces in causing movement.

5. Preliminary considerations bearing on the qualitative and the quantitative adequacy of the tidal forces.

6. Solar tidal force, acting from the beginning of the earth's planetary history, produced the older mountain ranges and was most powerful in the earlier geological periods (Archeozoic and Early Proterozoic). The earth probably had no satellite from the beginning of the Archeozoic down to the latter part of the Cretaceous, and throughout that long time was acted upon only by the solar tide; but from geological evidence we know that near the close of the Cretaceous period there came a relatively sudden and large increase in crustal movements and mountain-making, and that this increased activity has continued, probably in diminishing strength, down to the present time. Reasons for ascribing the great crustal movements to tidal forces were given above. Without a largely increased power of the tidal force, there is no way of explaining the world-wide increase of crustal movements and mountain-making which so strongly characterize the Tertiary Age.

7. How could there be a sudden increase in the power of the tidal force? Manifestly, in only one way, namely, through the acquisition by capture, directly out of space, of a relatively large planetoid body, like our present moon, and its permanent retention as a satellite. The moon's tidal force now acting on the earth is approximately 2 1/5th times more powerful than the present solar tidal force. The forces tending to move the continents and to make the mountain ranges were, therefore, increased by that much when the moon was first captured, and this increased force has continued to act ever since. It is concluded, therefore, that certain differential effects of the moon's attraction upon the crust of the earth, added to similar effects produced by the sun's attraction, have caused the continental crust-sheets to move from high toward low latitudes more actively since the moon's capture than during the preced-

ing Paleozoic periods, and that incidentally and subsidiary to the movements of the continental crust-sheets the great mountain ranges of the Tertiary belt were produced.

This much from the point of view of geology. But, since this theme lies in the borderland between geology and astronomy, a view from the astronomical side is really necessary for a complete presentation. The argument from the astronomical side, showing the soundness of the capture theory and its marvelous power to explain things, seems many times more potent, but it is not appropriate to the present occasion.

Read by title in the absence of the author.

ORIGIN OF THE STRUCTURAL FEATURES OF EASTERN MONTANA

BY W. T. THOM, JR., AND C. E. DOBBIN

(*Abstract*)

A structure contour map prepared by the writers shows the existing or restored configuration of the First Cat Creek or Dakota sandstone in eastern Montana. From this map it appears that the structural features of the area owe their origin to the deformation of a granitic basement in which there existed pre-Cretaceous lines of weakness, localizing the earth movements during the building of the Cordilleran system, and producing two systems of trends which combine to define the important structural features of the area. The effective compression was transmitted tangentially through the granite shell, and by hydraulic effect through the more plastic zone below, the two effects combining to produce monoclinal or block deformation, in the development of which the sedimentary rocks of the area played a passive rather than an active rôle.

PRE-CAMBRIAN PENEPLAIN IN THE ROCKY MOUNTAINS

BY C. J. HARES

Read by title.

EFFECT OF SALT AND GYPSUM ON THE FORMATION OF PARADOX AND OTHER VALLEYS OF SOUTHWESTERN COLORADO

BY SIDNEY POWERS

(*Abstract*)

Paradox, Gypsum, and Sinbad Valleys, in southwestern Colorado, east of the La Sal Mountains, Utah, may owe their present size and shape to the solution of a Pennsylvanian salt bed, permitting slumping and ready removal of the valley walls and subsequent flowage of the underlying gypsum and salt beds from hydration and release of pressure, forming salt anticlines and giving thickness of over 3,500 feet of gypsum, salt, and anhydrite, as shown by drilling.

Brief remarks were made by Messrs. Whitman Cross and James Gilluly.

RECENT LOCAL SUBSIDENCE OF THE GULF COAST OF TEXAS

BY WALLACE E. PRATT AND DOUGLAS W. JOHNSON

(*Abstract*)

A small portion of the Texas coast, known as the Goose Creek Oil Field, has within a few years suffered a subsidence amounting to approximately three feet at the maximum. Submergence of a part of the oil field created important legal problems, the solution of which depended upon the cause of subsidence. The physiographic phenomena are described, and the subsidence is attributed to extensive withdrawal of oil, gas, and sand from unconsolidated sediments of the Coastal Plain strata.

Brief remarks were made by Messrs. H. B. Kummel and W. T. Thom, Jr.

SAN PEDRO VALLEY, ARIZONA, AND THE GEOGRAPHIC CYCLE

BY KIRK BRYAN

(*Abstract*)

The mountains of the San Pedro Valley region in southern Arizona are the residual elevations resulting from an uplift that involved the Gila conglomerate. This well known formation, restricted according to Gilbert's original definition and the usage of Ransome, is a valley fill now deformed and dissected, but accumulated under arid conditions in enclosed or partly enclosed valleys. The conglomerate (fanglomerate) of the typical facies encircles unconsolidated fine-grained deposits laid down in the central areas of the original valleys. In the fine-grained deposits a large vertebrate fauna, determined by Gidley to be of late Pliocene age, has been found. The fine-grained deposits are of two types: (1) red clays with some sand and soft white limestone, (2) yellow sandy clays with sand, diatomaceous earth, and much gypsum. The first type lies in the southern part of the San Pedro Valley, is completely surrounded by conglomerate, and contains the best fossil localities. The second type occurs in the northern part of the valley and in numerous other places, particularly in the Ray Quadrangle. In spite of differences in lithology, which reflect unlike conditions of deposition, it is considered, on the basis of similar lithology and in the light of a small collection of bones from the yellow beds, that the two phases are synchronous and part of one formation. Since the fossils represent a fauna of Late Pliocene age and occur near the top of the formation, deposition of the Gila was completed by the end of Pliocene time and the uplift is subsequent but not necessarily much later.

The deformed Gila conglomerate everywhere rests unconformably on older rocks, including the Tertiary lavas, and obviously accumulated in basins under arid conditions. The nature of the deformation which produced the basins is not known, but it is certain that the mountains of that time were detached ranges located essentially, though not precisely, in the position of the present mountains, since nearly everywhere the conglomerate borders the mountains and fine-grained materials lie out in the intervening basins. The post-Gila deformation, which in this region closed the Pliocene epoch, produced the

existing mountains, which have not since been reelevated, although the region as a whole may have been broadly uplifted. The mountain uplift is of the block-fault type, as shown by detailed mapping of selected areas. However, many blocks suffered but little rotation and some of them are true horsts. The detailed distribution of the Gila formation, together with its minute faulting and crumpling, indicates that the mountain blocks were pushed through the less competent Gila, in which the stresses, due to the irregularities in the shape of the mountain blocks, were dissipated.

Following deformation, long-continued erosion formed a widespread surface, here termed the Tombstone pediment. The residuals above this surface consist of the harder rocks, or are located at points distant from main drainage lines. They have, therefore, all the characteristics of residuals in the normal cycle of erosion, save only their steep slopes. The slopes of mountains are, however, a function of the type of rock and the climate, when once the initial stage of development is over, and in arid regions the slopes of mountains are steeper than in areas of normal climate. Similarly, the erosion surface conforms to the drainage pattern in all its intricacies; is wide on main drainages; tapers into long, narrow triangles along minor streams; is enlarged on soft rocks, narrowed on hard rocks, and presents all the features of a peneplain in the normal cycle, except for steepness of slope. The slopes range from 50 to 200 feet per mile, gradients far in excess of those developed by streams in the old-age stage in humid regions. The Tombstone pediment is, therefore, an expression of peneplanation, though perhaps not complete base-leveling in an arid region.

Before the last residuals had been reduced, the Tombstone cycle was interrupted by the incision of the streams. At a lower level a second less complete pediment was developed. In this second, or Whetstone, pediment similar features were produced, but the cycle was again interrupted by the incision of the streams to the still lower level of the Aravaipa terrace. Below this terrace lie the valleys of the streams, once deeper than they now are because of a Recent fill that is now being removed in part by renewed erosion begun in 1883.

As the Tombstone pediment was not brought to completion, it affords only partial evidence as to the ultimate land form produced by erosion under arid conditions. In the limited areas where the residuals are most reduced, the divides between main drainages are tent-shaped, flat ridges having slopes of 1 to 3 degrees (100 to 300 feet per mile). The stream gradients are adjusted to the existing relation of water to load, but as the residuals disappear the quantity of débris should decrease and the grade flatten. Since this change would first take place near the divide, the divide should be first affected and the stream gradients should become slightly convex upward, but on the other hand the main streams, uncontrolled by the alluvial fans of tributaries, should shift laterally with ease and thus steepen the gradients of tributaries in the lower parts of their courses.

It is possible that wind action may at this stage become dominant over stream action, but the part of Arizona considered offers no evidence to this effect. Obviously, those areas having sufficient rainfall to support a cover of perennial grass are partly protected against wind work, and it may be that completion of the cycle by wind can only take place when the rainfall is lower than 5 inches annually.

SUBTERRANEAN STREAMS OF THE "ENDLESS CAVERNS," VIRGINIA

BY CHESTER A. REEDS

(*Abstract*)

Some of the underground stream courses in the "Endless Caverns," near New Market, Virginia, were explored and surveyed on three different occasions during 1925. That portion of the caverns which has been opened to tourists represents an older and upper stream channel which was abandoned many centuries ago by the subterranean brook which now flows at a level 40 to 60 feet lower down in the limestone rock. Many stalactites, stalagmites, pendant masses of natural rock, rock terraces, scalloped and etched surfaces appear in the dry upper course, while comparatively few secondary formations are to be found along the present waterway. In both instances the swiftly moving, acidulated waters have carved many a tortuous tunnel and left behind many a spacious chamber, while the slowly oozing waters, in the presence of the air of the cave, have tended to fill up these avenues with marvelous secondary deposits. The two well-defined watercourses in this cavern suggest that the underground stream was rejuvenated during the last uplift of the Shenandoah Valley plain. This is confirmed by the apparent rejuvenation of the surface streams of the region.

Read by title in the absence of the author.

PRINCIPLES OF EROSION IN HAWAII

BY CHESTER K. WENTWORTH

(*Abstract*)

The Hawaiian Islands are the subaerial portions of a line of volcanic cones which rise from fifteen to thirty thousand feet above the ocean floor in the North Pacific. Ranging from 69 to over 4,000 square miles in area and from about 1,500 to nearly 14,000 feet in height, the eight major islands are composed wholly of basaltic lavas in thin flows. Situated in the zone of the northeast trade winds, exhibiting variations of annual rainfall from 10 to 500 inches in a few miles, low annual and daily temperature ranges, and absence of frost below 2,500 feet, they present a combination of climatic factors departing widely from those which control weathering and erosion in most temperate continental areas. Add to these factors the susceptibility of the basalt to chemical weathering and the extraordinary porosity and permeability of the island masses, and the setting is created for the production of erosional features of an unusual character.

Chief among these are prodigious stream gulches, mainly short, very deep, steep-sided, and box-headed. Adjacent to these, and scarcely scarred by erosion of equal duration, are broad, sloping remnants of original conic surfaces. Sea cliffs of 100, 500, or even 1,000 feet rise at angles of 65 to 85 degrees from the water's edge on exposed shores, and certain inland features not wholly explained vie with the marine and fluviatile features in declivity. Some, but not all, of these are due to faulting. The declivity is the outstanding feature to be explained. Persistence of upland surface and the rarity of permanent

streams and of any sort of tributaries are notable. The outstanding causes which lead through the early stages of erosion to these results are the permeability of the rocks and the dominance of chemical weathering. Other factors play subordinate parts, and the whole may be traced through a process of land sculpture not wholly different from that of temperate regions, but differing enormously from it in the relative prominence of the different factors.

At this point, about 1 o'clock, the session was adjourned for luncheon.

Session of Wednesday Afternoon

The afternoon session was opened at 2 o'clock, in the Auditorium of Sterling Chemistry Laboratory, President Scott presiding, and proceeded immediately to the reading of scientific papers. Past President Coleman was called to the chair late in the afternoon, continuing to the close of the session.

Titles and Abstracts of Papers

Cenozoic History of the Northern Black Hills of South Dakota

by Louise Fillman [1]

(Abstract)

Diastrophism resulting in the formation of a structural dome involving pre-Cambrian, Paleozoic, and Mesozoic formations and accompanied by igneous intrusions occurred in the Black Hills area during the late Cretaceous or early Tertiary periods. Upon the flanks of the dome minor folds are superimposed in places.

By mid-Oligocene time great thicknesses of the uplifted strata had been removed by erosion and a peneplain developed. A subsequent differential uplift of approximately 2,700 feet in the central hills area and 200 feet on the plains resulted in renewed erosive activity of streams and the dissection of the old surfaces. Some of the evidences for the interrupted first cycle of erosion that will be presented are accordant summit levels, topography in late maturity in the central hills, antecedent streams, and fluviatile deposits on the uplands.

Two sets of terraces parallel to the present stream courses have been developed in later times. Several hypotheses for the development of these terraces will be entertained.

Geology of the Mingan Islands

by W. H. Twenhofel

(Abstract)

The Mingan Islands consist of a group of twelve large and several small islands margining the east coast of Quebec. They range in area from less

[1] Introduced by George F. Kay.

than an acre to about ten square miles. The large islands are more or less wooded. Except for lighthouse-keepers and their families on two of the islands, there are no permanent inhabitants. The places of highest elevation range to about 125 feet above sealevel, with a point or two on some of the largest islands which rise to about 150 feet.

The south shore of each island is low, and if cliffs are present they are not high. The north shores of most of the islands possess bold cliffs some of which exceed 100 feet in height. The east and west sides also commonly possess cliffs with their heights decreasing southward. This feature of the shore topography arises from the southerly inclinations of the composing strata.

The surface of nearly every island slopes southward. Some of the larger islands have an east-west trending depression extending across them into which the surface from the north slopes gently, but which is bordered on the south by a steeper slope. A marked feature of the surface of some of the islands is the "flower pots," or old sea stacks. These have been found up to about 100 feet above sealevel.

The rocks of the Mingan Islands consist of limestones and dolomites in which there are a few shale members. These have been placed in two formations—a lower, termed the Romaine formation, of Beekmantown age, and an upper, known as the Mingan formation. This is of Middle Ordovician age. It is believed that the Romaine strata rest directly on the pre-Cambrian crystallines.

Due to the presence of some zones of relatively weak strata, it has resulted that the islands fall into an inner and outer group, and the outer group in turn may be subdivided into two groups. The inner group contains Harbour, Little Romaine, Large Romaine (Montange), and Saint Genevieve islands. The inner side of Hunting Island and several of the salients of the mainland also belong to this group. These constitute the top of a dissected cuesta whose inner lowland is partly submerged and partly filled with marine and aqueoglacial deposits. In the outer group of islands are Parroquet, Mingan, Inner Birch, Outer Birch, Large, Quarry, Napisca, Eskimo, Quin, Sea Cow, Saint Charles, and the outer portion of Hunting Island. This group forms a double crested cuesta, due to the fact that a belt of relatively weak rock lies at the base of the Mingan formations. This belt is eroded out to form the channel between Inner and Outer Birch islands, and bays and low areas mark the places of its outcrop on Large, Quarry, Napisca, Eskimo, and Hunting islands and on Clearwater and Aummonite Points of the mainland.

Brief remarks were made by Prof. D. W. Johnson, with reply by the author.

LATE GLACIAL OSCILLATIONS OF LEVEL IN THE SAINT LAWRENCE-OTTAWA VALLEY[1]

BY JAMES WALTER GOLDTHWAIT

(*Abstract*)

The history of the emergence of the Saint Lawrence and Ottawa valleys from the late glacial sea appears to be much more complicated than has

[1] Published by permission of the Director of the Geological Survey of Canada.

generally been supposed. During the withdrawal of the ice-border that region seems to have risen and fallen several times while it came up to its present position.

Striking evidence of these oscillations was recognized by Antevs in 1924 in sections of marine deposits near Ottawa; and more evidence of the same kind was collected by Antevs and the present writer, for the Geological Survey of Canada, in 1925, at localities farther west and north. Successive deposits of marine clay of deep-water origin are separated by distinct erosion surfaces believed to register actual emergence of the localities between the two stages of deep-water deposition.

Attention has been called by Canadian investigators to wave-cut terraces and bluffs in districts where the marine clays are widespread and thick. They appear at several different levels and are not local, but can be traced long distances, failing only where the clay gives way to more resistant ground, like till or bedrock. They were obviously cut during the emergence of the valley from the sea. Evidence from deposits that formed at stream mouths near the sea-cliffs leads to the opinion that two of these terraces, at least, were cut while the sea was rising on the land and not simply during a halt in the uplift.

In the Baltic region three or four such oscillations of level have been recognized. In Canada there may have been more.

Brief remarks were made by Messrs. A. P. Coleman and Arthur Keith.

GLACIAL ORIGIN OF THE BISHOP CONGLOMERATE OF WYOMING, COLORADO, AND UTAH

BY C. J. HARES

(Abstract)

The origin of the Bishop conglomerate, first named the Wyoming conglomerate, has been a subject of much discussion ever since the Fortieth Parallel Survey, made in 1876, under the direction of Clarence King. It has been described by King, Powell, Hayden, Emmons, White, Irving, Veatch, Rich, Shultz, Ball, Lupton, Hancock, Sears, Gale, and others in many reports on the geology of the Uinta Mountains and surrounding territory. Some of these have mentioned it might contain glacial material. It was always classed as late Tertiary or Quaternary until Sears correlated it with the basal conglomerate of the Browns Park formation of Miocene (?) age. Rich, in an exhaustive paper, discarded the theory of its being of glacial origin for stream terraces.

Investigations during the summer of 1925 revealed the fact that large glaciers spread from the Uinta Mountains and other ranges in the Rocky Mountains at the time the Bishop conglomerate was deposited. The largest of these left huge boulders of Uinta quartzite on the south slope of Aspen Mountain, Wyoming, about fifty miles north of the Uinta Mountains. These boulders show glacially scoured, grooved, and planed surfaces. The largest boulder is over 20 feet long.

The top of Diamond Peak, Colorado, is covered by glacial debris estimated about 1,000 feet thick and composed mostly of Uinta quartzite. Many boulders are 5 to 10 feet in diameter. The tiptop boulder on the peak, at an elevation

of about 9,975 feet, is at least 8 feet long. The peak is isolated and 25 miles away from the crest of the Uintas.

The Bishop conglomerate is mostly outwash glacial gravels deposited in pre-Miocene and post-Eocene time and is not strictly a part of the Browns Park formation. It is a product of a great mid-Tertiary glacial epoch and deserves a distinct formational name.

Brief remarks were made by Messrs. A. P. Coleman, J. L. Rich, J. W. Gilluly, and R. W. Sayles.

WHAT IS THE DENVER FORMATION?

BY C. J. HARES

(*Abstract*)

The thesis is advanced that the upper 525 feet should not be classed with the lower 915 feet at the type locality at Green Mountain, Colorado. The lower part is well stratified shale, sandstone, and conglomerate, whereas the upper division is wholly conglomeratic, with no shales or sandstones observable. The conglomerate, while rather fine at the bottom of the upper division, becomes coarser toward the top, where boulders 2 to 4 feet in diameter are very common. The largest one is 6 feet through. The absence of good stratification suggests its probable glacial origin. Many of the boulders show flat faces, concave faces, grooved faces, and some are wedge-shaped. Many are subangular. None was found showing striations, but long exposure to weathering agencies would destroy striations. Good fresh exposures are not available.

Structurally, the two divisions are separable, for the lower one dips at high angles, while the upper is almost flat lying.

It is believed that two distinct lithologic units are classed in the Denver formation, one similar to the Arapahoe below and the other of entirely different character and seemingly of glacial origin of post-Eocene age. It is provisionally correlated with the post-Eocene pre-Miocene glacial evidence found elsewhere in the Rocky Mountain region.

Brief remarks were made by Dr. Whitman Cross.

POST-EOCENE-PRE-MIOCENE GLACIATION IN THE ROCKY MOUNTAINS

BY C. J. HARES

(*Abstract*)

Definite evidence was found last summer of a post-Eocene and pre-Miocene glacial epoch over much of the Rocky Mountain region. Extensive glaciers deployed from the Wind River, Uinta, Medicine Bow, Laramie, Front Range, and Bighorn Mountains; also probably from any mountains in the Rockies as high as the Laramie Range. The evidence consists of striated, grooved, smoothed, and rounded bedrock surfaces, rôches moutonnées, till, enormous erratic boulders far from their native outcrop and at high altitudes, outwash gravels and U-shaped valleys. This evidence is developed on pre-Cambrian

schist and granite, rests on the youngest Eocene formations, and occurs beneath formations classed as Oligocene and Miocene. This evidence of mid-Tertiary glaciation is found at high altitudes, ranging from 5,000 to over 10,000 feet, and occurs at consistent and concordant levels that mark a profound unconformity and possibly an extensive peneplain—a surface devoid of the present master streams.

The largest of these glaciers is here named the Sweetwater Glacier, since it extended from the Wind River Mountains down the Sweetwater Valley, a distance of at least 125 miles, was possibly 3,000 feet thick, and probably 30 miles wide, which is about the size of the present valley. Another big glacier was the Diamond Peak-Aspen Mountain Glacier, which extended at least 25 and probably 50 miles off the Uinta Mountains. The Encampment Glacier was at least 30 miles long and perhaps much longer. It apparently was made up of ice from both the Medicine Bow and Sierra Madre Mountains. The Laramie Glacier left boulders 30 feet long over 25 miles from their bedrock. The Kingsbury Glacier deployed from Cloud Peak nearly to Buffalo, Wyoming. In the Denver Basin glacial debris is many miles from its source.

Compared to the Pleistocene glaciers in the Rocky Mountains, the mid-Tertiary ones seemingly were from 20 to 25 times as long, much wider, and thicker. Whether these figures are a measure of their greater importance and show that they covered that much more geologic time is a question, but the estimate seems reasonable.

Most of the Tertiary vulcanism in the Rocky Mountains is subsequent to this glacial epoch. These numerous outbursts of igneous intrusions may have had some influence on the ending of the glaciation.

Since mid-Tertiary glacial epoch the Rocky Mountains have been uplifted epeirogenically several hundred feet. The altitude of the marine Tertiary inland in the Gulf embayment may be the measure of this uplift. The establishment of the present drainage system postdates the glaciation and also this uplift. The course of the Sweetwater River was clearly determined by the course of the Sweetwater Glacier. Other streams may have had their positions influenced by the mid-Tertiary glaciation.

A marked change in the fossils occurs at the Tertiary glacial epoch. The Eocene has many coal deposits, whereas none are found in later beds in the Rocky Mountain region. A noticeable change occurs also in the vertebrates. Invertebrates are plentiful in the Eocene, but are rare in the later formations. The climatic change created a break in the life forms.

The Eocene (?) glaciation described by Atwood in the San Juan Mountains, Colorado, is tentatively correlated with the post-Eocene, pre-Miocene glacial epoch. When more fossil collections are obtained from the formations associated with the mid-Tertiary glaciation and those already collected are studied with reference to this glaciation, its exact age may be determined. The age of some of these formations has not yet been determined as accurately as desired.

Brief remarks were made by Prof. W. B. Scott.

CONTROLLING CAUSE OF PERIODIC GLACIATION

BY CHARLES KEYES

(*Abstract*)

It appears not to be so generally known as it should that, in the form of a purely speculative deduction, the idea of Glacial epochs initiated by changing eccentricity of the earth's orbit was advanced long before the concept itself of one-time existence of continental glaciers took concrete form. Recent analysis of the circumstances and conditions which lead to the failure of Croll, for instance, to work out a satisfactory astronomical hypothesis for the Great Ice Age brings out numbers of essential features hitherto completely overlooked or then impossible to determine for lack of pertinent observed facts.

No matter how intense it is, mere cold can not, of course, bring on a Glacial epoch, but refrigerating conditions which result in the aphelion winters becoming 50 degrees colder and 30-odd days longer than ordinary may be expected to develop essential, and indeed controlling, influences. Existing climatic conditions are simply intensified and present climatic zones are pushed toward the equator. It takes no very profound or extensive excursions into the realm of obtruse celestial mechanics to figure out just about what the net climatic results must be.

Evident regularity in the repeated returns of Glacial conditions, as particularly expressed in the till-sheets, is at this stage of our knowledge a most remarkable phase of the Glacial problem. In one way, at least, the destructive criticism of the astronomical theory leveled against Croll, for instance, is highly productive of good and substantial results, but in a manner little suspected at the time by the astronomers. Their savage taunt and seemingly unanswerable assertion, that there exist no physical facts to support the cosmical contention, is fully met, independently and without malice aforethought, by the geologists, in overwhelming testimony, through the dislodgment of no less than seven distinct till-sheets separated by soil layers, representing as many Glacial epochs, the establishment of their cycle at about 100,000 years, and the fixing of the date of the last Ice Age at not more than 15,000 or 20,000 years ago. So that Calvin's recent prediction for the early discovery of more till-sheets may speedily take on something more than merely optimistic outlook.

Substitution of a perfected equation for that early and famous one devised by Leverrier by which to determine the constants of planetary motions, recalculation of the values and limits of earth's orbital eccentricity at much shorter intervals than formerly adopted—10,000 years instead of 50,000—recent realization of the multiple character of glaciation as detected in the products observed in the field, seeming coincidence of the relative maxima extensions of polarine ice-caps with the points of maxima eccentricities, recent acquirement of adequate observational data meeting the demands of cosmical hypothesis upon the phenomena of continental glaciation, recognition of the proper scope of numerous contributory or modifying influences on Glacial cycles, some of which are often claimed to be dominant, and failure of all other hypotheses to explain satisfactorily the rhythmic recurrence of Great Ice Ages and all their collateral phenomena, appear not only to remove every objection

which was formerly so often urged against a cosmical explanation of glaciation, but to furnish amply broad foundation for following the Glacial cycles through the geological ages, and perhaps for supplying a means of calculating the duration of geological time as precisely as now we figure the epochs of human history within the span of the Christian Era.

The recalculated values, as worked out by the late John N. Stockwell, are assembled in a table, while those figures spanning the last million years are plotted on a compressed curve and represented on a chart.

Doubtless the two chief reasons why we are so slow to detect traces of additional till-sheets and field evidences of other Glacial epochs than the few of which we are cognizant, are that the older till-sheets are so speedily effaced by the advances of the newer glaciers, and that we do not know yet just where to look for their remnants. In the upper Mississippi Valley, for instance, favorable locations are evidently in the deep, "pre-Glacial" gorges of east- or west-flowing streams, especially on the north sides, where in sheltered nooks the ancient tills may still not be entirely removed through the later cleaning out of the old stream channels. Some old river valleys now filled up are buried by the deposits of recent dates, but where these are disturbed through excavation, artificial or otherwise, there are apt to be revealed complex tills.

The most hopeful perspective for a long succession of ancient till-sheets is the Rocky Mountain region. For the revelation of Tertiary glacial deposits we now have a clue awaiting our inspection, that whole magnificent pile of epirotic or continental deposits of Utah, Wyoming, and Montana. In the four miles of strata the possibilities are simply immense. Many of the conglomerates which are commonly ascribed to channel fillings are long looked upon as possibly being glacial débris.

Read by title in the absence of the author.

GLACIAL GEOLOGY OF CAPE BRETON ISLAND, NOVA SCOTIA

BY KIRTLEY F. MATHER

(*Abstract*)

In a recent publication[1] J. W. Goldthwait discusses the glacial history of Cape Breton Island and indicates his belief that the entire island was covered by ice which moved southeastward across the Gulf of Saint Lawrence. He further suggests the possibility that a portion of Cape Breton Island adjacent to Sydney was also affected by ice which moved eastward and northeastward from the New Brunswick Highlands. More recently L. W. Fernald[2] has quoted A. P. Coleman to the effect that there is "a considerable unglaciated area at the northeast end of Cape Breton Island. Here the ice probably reached no higher than 500 feet, and there are many square miles above 1,000 feet. Inverness is a good point to visit an unglaciated area."

During the summer of 1925, while engaged in structural and stratigraphic studies on Cape Breton Island, I had opportunity to observe the glacial

[1] Physiography of Nova Scotia. Geological Survey of Canada, Memoir 140, 1924.

[2] Persistence of plants in unglaciated areas of boreal America. Memoirs, American Academy of Arts and Sciences, vol. 15, no. 3, 1925, p. 314.

features at several widely separated localities on the island. Heavy masses of glacial moraine are widely distributed on the undulating lowlands, which rise to elevations of about 400 feet and which occupy, all told, about one-third of the area of Cape Breton. At many places on these lowlands the solution of gypsum has developed a karst topography which, in places, simulates the topography of a terminal or ground moraine. Elsewhere a veneer of till, 10 to 50 feet in thickness, displays the characteristic knob and kettle topography of well-defined glacial moraines. Among the many localities with conspicuous glacial drift may be noted Whycocomagh; the valleys leading from the Mabou Highlands south of Inverness; the shores of Seal Cove near Saint Ann; Indian Brook near entrance to Saint Anns Bay; Broad Cove Run near Warren Lake, north of Ingonish. Kames, sand plains, and other fluvio-glacial deposits were noted at several localities, as, for example, in the vicinity of Strathlorne, about four miles south of Inverness. A scanty veneer of glacial drift is scattered over the high, flat summit of the partially dissected tableland with an altitude of 800 to 1,000 feet, known as the Mabou Highlands. The summit of Salt Mountain, which rises abruptly to an altitude of about 720 feet, overlooking Whycocomagh, displays characteristic rôches moutonnées sculptured from the coarse conglomerate composing that mountain and only slightly weathered since the withdrawal of the ice.

A broad upland terminating eastward in Cape Smoky stands at an elevation of 900 to 1,200 feet above sealevel in the northern part of the island. Part of its surface is covered by arkosic soil and a thick mantle of residual grit, the product of local disintegration of the coarse granite which forms that highland. Careful search in the vicinity of the automobile highway between Wreck Cove and Ingonish revealed no foreign or glaciated stones on the summit. With full regard for the exceptional rapidity of rock disintegration where coarse granites are exposed to such a climate as that of Cape Breton Island, it is extremely unlikely that the amount of weathering displayed on this upland could have been accomplished since Pleistocene time. Glacial drift occurs at least as high as 800 feet along the road descending toward Ingonish, but the higher lands along the eastern margin of the upland appear to have escaped glaciation.

The conclusion is reached that during the Glacial epoch the ice from the Laurentian region moved southeastward across the Gulf of Saint Lawrence to a terminal line which was quite irregular and approximately coincided with the eastern and southeastern shores of Cape Breton Island. Near the margin of this ice-sheet the ice was so thin that it was strongly influenced by the rugged topography across which it was moving. Tongues of ice projected far beyond the main body where lands were low; where bold highlands breasted the glacial flood the forward movement of the ice was greatly retarded. Some of the highlands were weakly glaciated, while certain tablelands, especially those which projected far toward the northeast, north of Saint Anns Bay, failed to be completely covered.

It is further suggested that the northeastward movement of the ice in the vicinity of Sydney is due to deflection of the marginal ice by the troughs and cliffs leading northeastward from the Great Bras d'Or basin.

The relation of well-defined morainic topography to sealevel at many points along Cape Breton Island indicates that there has been no relative uplift of

that island since the withdrawal of the ice. Its strand is everywhere a shoreline of submergence. No elevated beaches or wave-cut cliffs were observed upon its borders. This absence of postglacial uplift is, of course, in keeping with the conclusion that the eastward terminus of the Laurentian ice-sheet was not far from the east margin of the present landmass.

Brief remarks were made by Messrs. A. P. Coleman, Arthur Keith, J. W. Goldthwait, and C. W. Brown.

GLACIATION IN THE SAN GABRIEL MOUNTAINS, CALIFORNIA

BY WILLIAM J. MILLER

(*Abstract*)

Recently discovered evidence that several glaciers once existed in the San Gabriel Mountains, within 30 miles of the site of the business center of Los Angeles, will be set forth in this paper. The size of the glaciers, the moraines, the amount of ice erosion, a glacial lake-basin, the age of the glaciation, and the factors favorable to the glaciation will be discussed.

VARVED CLAYS AT HAVERSTRAW, NEW YORK

BY CHESTER A. REEDS

(*Abstract*)

During September and October, 1925, samples of the varved clays exposed in the Haverstraw district were collected in copper trays 24 inches × 2 inches × 1 inch from four rather widely separated pits and taken to New York, where they were treated and studied in the laboratories of the American Museum of Natural History. In the Renn and Archer pits, near Jones Point, the seasonal layers dip at angles of five to seven degrees away from the Hudson River front. In the various faces exposed, a continuous section of 73 feet of sediments was collected, which contains 541 varves. Along the west margin of these pits and approximately at sealevel, two feet of fine gravel, followed by three feet of peat, appear above the clay.

In the Washburn-Fowler pit, a half mile northeast of the West Haverstraw station, a 19-foot section containing 240 varves was taken from a trench face which had been exposed in the marshy ground alongside the Minisceongo Creek.

Samples were also collected from the Hornbecker and Dunnigan pits, which occupy the face of the 60-foot escarpment a short distance to the northeast of the West Haverstraw station. A 35-foot section of the Dunnigan pit yielded 540 varves, and a 25-foot section of the Hornbecker pit 418 varves. Although these pits are a quarter of a mile apart, correlations were established without difficulty between the varves of the two pits. Numerous slidden zones appear in the upper beds of these two pits beneath the 20 ± feet of top-set and fore-set beds of sand and gravel which rest upon the clay.

The clay deposits extend from well below sealevel to approximately 60 feet above mean high tide. In the 127 feet of clay represented by the samples, 1,321 varves were noted, but this record does not include the entire section.

for nowhere was the bottom of the clay reached; neither were correlations established between three of the four localities studied. In most instances the clay is overlain by top-set and fore-set beds of sand and gravel of early post-Glacial age.

Read by title in the absence of the author.

LATE QUATERNARY CHANGES OF LEVEL IN SOUTHERN NEW ENGLAND

BY ERNST ANTEVS[1]

(*Abstract*)

At the climax of the latest glaciation, the sealevel stood at least a few hundred feet lower than at present, because large quantities of water were stored in ice. The zero-isobase, which runs south of Boston, marks points which at the release from the ice stood exactly as much below their modern level as the sealevel did. A zone outside the zero-isobase stood higher in relation to the sea than at the present time. The amount increased in peripheral direction. Whether a belt stood actually higher than today, or not, is difficult to tell. Parts of the continental shelf off New England may have formed land.

On Narragansett Bay, Rhode Island, varved late glacial clays, deposited in perfectly fresh water, occur in open exposure at and above sealevel. Glacifluvial sand and gravel, associated with these clays, at Providence, reach an altitude of about 120 feet, and sealevel on the latitude of 41½ degrees north (R. W. Sayles). The barrier of the lake in which these sediments were formed may have been situated on the line Montauk Point-Block Island-Marthas Vineyard. A land bridge here postulates that the region stood at least 120 feet higher in relation to sealevel, which is quite reasonable. The northward tilt of the earth's crust and the relatively lower areas inside the line mentioned may have enabled the formation of a lake, which, as the ice-border receded, extended up Narragansett Bay, Long Island Sound, and the river valleys to the north.

At Hackensack, New Jersey, late glacial fresh-water clays occur at and below the level of the sea. The barrier of the late glacial lake in the Hackensack region may have lain on the line Sandy Hook-Long Island, which tract need only have stood some 30 feet higher in relation to sealevel. However, the southern shore lay possibly farther out.

The chief later events have been uplift of land with, in northward direction, increasing amount, eventually sinking of part of the continental shelf, and rise of the sealevel. In the zone between Haverstraw and Albany the upheaval of land proceeded more rapidly than the rise of the sealevel, as shown by the lowering of the level of erosion to below the modern stand (J. B. Woodworth). The Boston region simultaneously stood more than 20 feet higher in relation to sealevel than at present (Douglas Johnson). This high position was held a comparatively short time ago, probably during the early part of the post-glacial temperature maximum, judging from conditions found by H. W. Shimer at Boston—that is, 7,000 to 5,000 years ago. Subsequently a transgression (sinking of land, or rise of sealevel, or both) of more than

[1] Introduced by Robert W. Sayles.

20 feet has taken place. The existing relation of land and sea was reached already several thousand years ago (Douglas Johnson). In the region of Peekskill on the Hudson, however, the transgression may have been followed by a slight regression.

NEW DISCOVERIES RELATING TO THE WASATCH FAULT PROBLEM

BY FREDERICK J. PACK[1]

(*Abstract*)

Immediately beneath the present land surface the Wasatch fault-plane dips at an angle of practically 70 degrees, while the slope of the escarpment is seldom greater than 30 degrees. Coincidence of the land surface with the dividing line between the uneroded fault-plane below and the highly dissected scarp above is interpreted to mean that fault displacement has quantitatively kept pace with deposition on the downthrown block.

SOME PHENOMENA OF THE SAINT LAWRENCE EARTHQUAKE

BY ARTHUR KEITH

Read by title in the absence of the author.

DEVELOPMENT OF THE THEORY OF MULTIPLE GLACIATION IN NORTH AMERICA

BY FREDERIK T. THWAITES

(*Abstract*)

Some doubts having been raised as to the validity of the current subdivisions of the Pleistocene into glacial and interglacial stages, the literature on this subject was reviewed so far as it concerns North America. The influence of Croll's hypothesis of the cause of glaciation started the search for evidences of interglacial intervals. On the other hand, those who rejected that theory in favor of elevation of the continents always favored a short, single episode of glaciation, so that rival views on the origin of the Glacial period colored the opinions of students of the Pleistocene. The first to publish descriptions of organic remains in the drift which were called *interglacial* were N. H. Winchell and Edward Orton, in 1873. In 1893 Salisbury published the only categorical summary of the criteria for the determination of different ages of glacial drift that has ever appeared. In the following year Chamberlin gave geographical names to three ages of drift. By 1898 six glacial stages and four of the five interglacial intervals between them had been named. Since 1900, however, a spirit of conservatism has appeared and Leverett has attempted to reduce the number of glacial stages to four. This precipitated a controversy over the Iowan stage. The subject is discussed upon an areal basis in order to make the great number of references more clear. No extended discussion of criteria is attempted, but the conclusion is reached that while complexity of the glacial succession in southern latitudes

[1] Introduced by James F. Kemp.

and long duration of the Pleistocene have been well established, there is still room for question as to the number of distinct glacial stages in the United States and as to the disappearance of the ice from the glacial centers in Canada more than once.

Read by title in the absence of the author.

RESOLUTION OF THANKS

The Geological Society desires to express its appreciation of the delightful hospitality extended by the authorities of Yale University for its annual meeting of 1925. The unusually large numbers attending the meetings have made necessary more than ordinary efforts on the part of the local committee.

All the arrangements have been so efficient and all plans so agreeable and pleasant, that the Yale meeting will long be remembered.

HARRY FIELDING REID, *Chairman.*
A. P. COLEMAN.
JAMES F. KEMP.

Chairman Coleman then announced that the business, the scientific sessions, and other activities of the annual meeting of 1925 had been completed, and on motion the thirty-eighth annual meeting adjourned at 5 o'clock.

CHARLES P. BERKEY,
Secretary.

Register of the New Haven Meeting, 1925

FELLOWS

Frank D. Adams
Frank J. Alcock
Harold L. Alling
George H. Ashley
H. Foster Bain
Florence Bascom
R. S. Bassler
Edson S. Bastin
Alan M. Bateman
W. S. Bayley
Charles P. Berkey
N. L. Bowen
J. A. Bownocker
T. M. Broderick
Charles W. Brown
Kirk Bryan
A. F. Buddington
L. D. Burling
Walter H. Bucher
B. S. Butler
Charles Camsell
J. Ernest Carman
George H. Chadwick
Arthur P. Coleman
R. J. Colony
Alja R. Crook
Whitman Cross
Joseph A. Cushman
Nelson C. Dale
R. A. Daly
Edward S. Dana
Nelson H. Darton
Arthur L. Day
E. De Golyer
Carl O. Dunbar
Arthur S. Eakle
C. N. Fenner
H. G. Ferguson
Charles R. Fettke
August F. Foerste
William E. Ford
Wilbur G. Foye
J. J. Galloway
J. W. Gidley
C. W. Gilmore
Winifred Goldring
J. W. Goldthwait
C. E. Gordon
Herbert E. Gregory
William K. Gregory
U. S. Grant
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C. J. Hares
Chris. A. Hartnagel
Albert O. Hayes
K. C. Heald
Frank L. Hess
Donnel F. Hewett
Thomas McDougall Hills
William H. Hobbs
W. O. Hotchkiss
Ernest Howe
George S. Hume
Walter F. Hunt
Douglas Johnson
Roswell H. Johnson
George F. Kay
James F. Kemp
E. M. Kindle
Adolph Knopf
Eleanora Bliss Knopf
Edward H. Kraus
Henry B. Kummel
George F. Kunz
Alfred C. Lane
Esper S. Larsen

ANDREW C. LAWSON
CHARLES K. LEITH
WALDEMAR LINDGREN
HOMER P. LITTLE
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R. S. LULL
KIRTLEY F. MATHER
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EDWARD B. MATHEWS
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HEINRICH RIES
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WILLIAM J. SINCLAIR
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PHILIP S. SMITH
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MALCOLM R. THORPE
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EDGAR T. WHERRY
DAVID WHITE
HERBERT P. WHITLOCK
GEORGE R. WIELAND
A. N. WINCHELL

FELLOW-ELECT

ERNST VALDEMAR ANTEVS

In addition to the foregoing, there were registered at the meeting 195 members of affiliated societies and visitors.

Lists of former Officers and Meetings, with Dates

By recommendation of the Council, a complete list of past officers, with the dates of their service, is printed in the Proceedings.

PRESIDENTS

1889.	James Hall	1907.	C. R. Van Hise
1890.	James D. Dana	1908.	Samuel Calvin
1891.	Alexander Winchell	1909.	Grove K. Gilbert
1892.	G. K. Gilbert	1910.	Arnold Hague
1893.	J. William Dawson	1911.	William M. Davis
1894.	T. C. Chamberlin	1912.	H. L. Fairchild
1895.	N. S. Shaler	1913.	Eugene A. Smith
1896.	Joseph Le Conte	1914.	George F. Becker
1897.	Edward Orton	1915.	Arthur P. Coleman
1898.	J. J. Stevenson	1916.	John M. Clarke
1899.	B. K. Emerson	1917.	Frank D. Adams
1900.	G. M. Dawson	1918.	Whitman Cross
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1902.	N. H. Winchell	1920.	I. C. White
1903.	S. F. Emmons	1921.	James F. Kemp
1904.	J. C. Branner	1922.	Charles Schuchert
1905.	Raphael Pumpelly	1923.	David White
1906.	I. C. Russell	1924.	Waldemar Lindgren

1925. William B. Scott

VICE-PRESIDENTS

(*Not including ex-officio Vice-Presidents representing the affiliated Societies*)

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1890.	J. S. Newberry	A. Winchell
1891.	G. K. Gilbert	T. C. Chamberlin
1892.	J. W. Dawson	T. C Chamberlin
1893.	T. C. Chamberlin	J. J. Stevenson
1894.	N. S. Shaler	G. H. Williams
1895.	Joseph Le Conte	Charles H. Hitchcock
1896.	Charles H. Hitchcock	Edward Orton
1897.	J. J. Stevenson	B. K. Emerson
1898.	B. K. Emerson	G. M. Dawson
1899.	G. M. Dawson	C. D. Walcott
1900.	C. D. Walcott	N. H. Winchell
1901.	N. H. Winchell	S. F. Emmons
1902.	S. F. Emmons	J. C. Branner
1903.	Arnold Hague	H. S. Williams
1904.	H. S. Williams	Samuel Calvin
1905.	Samuel Calvin	W. M. Davis
1906.	W. M. Davis	E. A. Smith
1907.	J. S. Diller	A. P. Coleman

1908.	George F. Becker	A. C. Lawson
1909.	Frank D. Adams	John M. Clarke
1910.	Charles Schuchert	A. P. Low
1911.	William North Rice	
1912.	Israel C. White	
1913.	James F. Kemp	R. D. Salisbury
1914.	Waldemar Lindgren	Horace B. Patton
1915.	L. V. Pirsson	H. P. Cushing
1916.	J. P. Iddings	H. F. Reid
1917.	A. C. Lawson	W. D. Matthew
1918.	Bailey Willis	Frank Leverett
1919	R. A. F. Penrose, Jr.	Herbert E. Gregory
1920.	George P. Merrill	W. G. Miller
1921.	J. B. Woodworth	Arthur Keith
1922.	Henry S. Washington	Robert T. Hill
1923.	W. H. Hobbs	W. H. Emmons
1924.	William A. Parks	Johan A. Udden
1925.	Reginald W. Brock	Marius R. Campbell

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1917–	E. B. Mathews

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1891–1906.	H. L. Fairchild
1907–1922.	E. O. Hovey
1923–	Charles P. Berkey

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1893–	J. Stanley-Brown

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1890.	J. W. Powell	G. M. Dawson	C. H. Hitchcock
1891.	George M. Dawson	J. C. Branner	
1892.	N. H. Winchell	H. S. Williams	
1893.	E. A. Smith	C. D. Walcott	
1894.	F. D. Adams	I. C. Russell	
1895.	R. W. Ells	C. R. Van Hise	
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1905.	H. M. Ami	J. F. Kemp	

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1910.	J. B. Woodworth	C. S. Prosser
1911.	A. H. Purdue	Heinrich Ries
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1914.	R. A. F. Penrose, Jr.	W. W. Atwood
1915.	Charles K. Leith	Thomas L. Watson
1916.	Frank B. Taylor	Charles P. Berkey
1917.	Arthur L. Day	William H. Emmons
1918.	Joseph Barrell	R. A. Daly
1919.	William S. Bayley	Eugene W. Shaw
1920.	T. W. Vaughan	George F. Kay
1921.	L. C. Graton	G. D. Louderback
1922.	E. S. Bastin	L. G. Westgate
1923.	E. O. Hovey	A. H. Brooks
	Charles Camsell	J. A. Bownocker
1924.	Fred. E. Wright	William H. Twenhofel
1925.	U. S. Grant	Florence Bascom

ANNUAL AND SEMI-ANNUAL MEETING PLACES

1888. Ithaca, New York.
1889. Toronto, Canada, August.
New York City, December.
1890. Indianapolis, Indiana, August.
Washington, D. C., December.
1891. Washington, D. C., August.
Columbus, Ohio, December.
1892. Rochester, New York, August.
Ottawa, Canada, December.
1893. Madison, Wisconsin, August.
Boston, Massachusetts, December.
1894. Brooklyn, New York, August.
Baltimore, Maryland, December.
1895. Springfield, Massachusetts, August.
Philadelphia, Pennsylvania, December.
1896. Buffalo, New York, August.
Washington, D. C., December.
1897. Detroit, Michigan, August.
Montreal, Canada, December.
1898. Boston, Massachusetts, August.
New York City, December.
1899. Columbus, Ohio, August.
Washington, D. C., December.
1900. New York City, June.
Albany, New York, December.

1901. Denver, Colorado, August.
Rochester, New York, December.
1902. Pittsburgh, Pennsylvania, July.
Washington, D. C., December.
1903. Saint Louis, Missouri, December.
1904. Philadelphia, Pennsylvania, December.
1905. Ottawa, Canada, December.
1906. New York City, December.
1907. Albuquerque, New Mexico, December.
1908. Baltimore, Maryland, December.
1909. Cambridge and Boston, Massachusetts, December.
1910. Pittsburgh, Pennsylvania, December.
1911. Washington, D. C., December.
1912. New Haven, Connecticut, December.
1913. Princeton, New Jersey, December.
1914. Philadelphia, Pennsylvania, December.
1915. Leland Stanford, Jr., University, California, August.
Washington, D. C., December.
1916. Albany, New York, December.
1917. Saint Louis, Missouri, December.
1918. Baltimore, Maryland, December.
1919. Boston, Massachusetts, December.
1920. Chicago, Illinois, December.
1921. Amherst, Massachusetts, December.
1922. Ann Arbor, Michigan, December.
1923. Washington, D. C., December.
1924. Ithaca, New York, December.
1925. New Haven, Connecticut, December.

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MEMBERSHIP, 1926

CORRESPONDENTS

BARROIS, CHARLES, Lille, France. Dec., 1909.
BRÖGGER, W. C., Christiania, Norway. Dec., 1909.
DAVID, SIR TANNATT WILLIAM EDGEWORTH, Sydney, New South Wales. Dec., 1923.
DE GEER, BARON GERHARD, Stockholm, Sweden. Dec., 1910.
DE MARGERIE, EMMANUEL, Strassburg, Alsace, France. Dec., 1921.
HARKER, ALFRED, Cambridge, England. Dec., 1924.
HEIM, ALBERT, Zurich, Switzerland. Dec., 1909.
KAYSER, EMANUEL, Marburg, Germany. Dec., 1909.
KIAER, JOHAN, Christiania, Norway. Dec., 1925.
KILIAN, W., Grenoble, France. Dec., 1912.
KOTO, BUNJIRO, Tokyo, Japan. Dec., 1923.
LACROIX, FRANÇOIS ANTOINE ALFRED, Paris, France. Dec., 1923.
MOLENGRAAFF, GUSTAAF ADOLF FREDERIK, Delft, Holland. Dec., 1923.
ROGERS, ARTHUR WILLIAM, Cape Town, South Africa. Dec., 1924.
SOLLAS, WILLIAM JOHNSON, Oxford, England. Dec., 1925.
SEDERHOLM, JAKOB JOHANNES, Helsingfors, Finland. Dec., 1923.
TIETZE, EMIL, Vienna, Austria. Dec., 1910.
VOGT, J. H. L., Christiania, Norway. Dec., 1925.
WOODWARD, ARTHUR SMITH, London, England. Dec., 1923.

FELLOWS

* Indicates Original Fellows (see article III of Constitution)

ABBE, CLEVELAND, JR., 105 Highland Place, Ithaca, N. Y. August, 1899.
ADAMS, FRANK DAWSON, McGill University, Montreal, Canada. Dec., 1889.
ADAMS, GEORGE I., University of Alabama, Tuscaloosa, Ala. Dec., 1902.
ADAMS, LEASON H., Geophysical Laboratory, Washington, D. C. Dec., 1922.
ADKINS, WALTER S., c/o American University Union, 173 Blvd. St. Germain, Paris, France. Dec., 1921.
ALCOCK, F. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
ALDEN, WILLIAM C., U. S. Geological Survey, Washington, D. C. Dec., 1909.
ALDRICH, TRUMAN H., 1026 Glen Iris Ave., Birmingham, Ala. May, 1889.
ALLAN, JOHN A., University of Alberta, Edmonton, Alberta, Canada. Dec., 1914.
ALLEN, EUGENE T., Geophysical Laboratory, Washington, D. C. Dec., 1922.
ALLEN, R. C., 1202 Hanna Bldg., Cleveland, Ohio. Dec., 1911.
ALLING, H. L., University of Rochester, Rochester, N. Y. Dec., 1920.
AMI, HENRY M., Victoria Museum, Room 105, Ottawa, Canada. Dec., 1889.
ANDERSON, FRANK M., State Mining Bureau, 2604 Ætna St., Berkeley, Calif. Dec., 1902.
ANDERSON, ROBERT V., Menlo Park, Calif. Dec., 1911.
ANDREWS, E. C., Geological Survey of New South Wales, Sydney, New South Wales. Dec., 1920.
ANTEVS, ERNST V., Geological Museum, Harvard University, Cambridge, Mass. Dec., 1925.

ARNOLD, RALPH, 639 South Spring St., Los Angeles, Calif. Dec., 1904.
ASHLEY, GEORGE HALL, State Capitol, Harrisburg, Pa. August, 1895.
ATWOOD, WALLACE WALTER, Clark University, Worcester, Mass. Dec., 1909.
AURIN, FRITZ L., Marland Oil Co., Ponca City, Okla. Dec., 1925.
BAGG, RUFUS MATHER, JR., 7 Brokaw Place, Appleton, Wis. Dec., 1896.
BAIN, H. FOSTER, c/o Amer. Inst. Mining Engineers, 29 W. 39th St., New York, N. Y. Dec., 1895.
BAKER, MANLEY BENSON, School of Mining, Kingston, Ontario. Dec., 1911.
BALDWIN, S. PRENTISS, 11025 East Blvd., Cleveland, Ohio. August, 1895.
BALL, MAX WAITE, 1104 First Natl. Bank Bldg., Denver, Colo. Dec., 1924.
BALL, SYDNEY H., 42 Broadway, New York City. Dec., 1905.
BANCROFT, JOSEPH A., McGill University, Montreal, Canada. Dec., 1914.
BARBOUR, ERWIN HINCKLEY, University of Nebraska, Lincoln, Neb. Dec., 1896.
BARRETT, LESLIE PARK, Geol. Surv. of Michigan, Lansing, Mich. Dec., 1923.
BARTON, DONALD C., Amerada Petr. Corp., Houston, Texas. Dec., 1921.
BARTON, GEORGE H., Boston Soc. of Nat. History, Boston, Mass. Aug., 1890.
BARTSCH, PAUL, U. S. National Museum, Washington, D. C. Dec., 1917.
BASCOM, FLORENCE, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.
BASSLER, RAY SMITH, U. S. National Museum, Washington, D. C. Dec., 1906.
BASTIN, EDSON S., University of Chicago, Chicago, Ill. Dec., 1909.
BATEMAN, ALAN MARA, Yale University, New Haven, Conn. Dec., 1916.
BAUER, CLYDE MAX, P. O. Box 972, Amarillo, Texas. Dec., 1923.
BAYLEY, WILLIAM S., University of Illinois, Urbana, Ill. Dec., 1888.
BEEDE, JOSHUA W., 1201 S. David St., San Angelo, Texas. Dec., 1902.
BEEKLY, ALBERT L., 1106 Cosden Bldg., Tulsa, Okla. Dec., 1925.
BELL, WALTER A., Victoria Memorial Museum, Ottawa, Canada. Dec., 1923.
BENSON, W. N., University of Otago, Dunedin, New Zealand. Dec., 1919.
BERKEY, CHARLES P., Columbia University, New York, N. Y. August, 1901.
BERRY, EDWARD WILBER, Johns Hopkins University, Baltimore, Md. Dec., 1909.
BEYER, SAMUEL WALKER, Iowa Agricultural College, Ames, Iowa. Dec., 1896.
BILLINGSLEY, PAUL, 605 Pioneer Bldg., Seattle, Wash. Dec., 1922.
BLACKWELDER, ELIOT, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1908.
BOUTWELL, JOHN M., Natl. Copper Bank, Salt Lake City, Utah. Dec., 1905.
BOWEN, CHARLES F., c/o Standard Oil Co., 26 Broadway, New York City. Dec., 1916.
BOWEN, N. L., Geophysical Laboratory, Washington, D. C. Dec., 1917.
BOWIE, WILLIAM, U. S. Coast and Geodetic Survey, Washington, D. C. Dec., 1919.
BOWMAN, ISAIAH, American Geographical Society, Broadway at 156th St., New York City. Dec., 1924.
BOWNOCKER, JOHN ADAMS, Ohio State University, Columbus, Ohio. Dec., 1904.
BRANSON, EDWIN BAYER, University of Missouri, Columbia, Mo. Dec., 1911.
BRETZ, J HARLEN, University of Chicago, Chicago, Ill. Dec., 1917.
BRIGHAM, ALBERT PERRY, Colgate University, Hamilton, N. Y. Dec., 1893.
BROCK, REGINALD W., Univ. of British Columbia, Vancouver, B. C. Dec., 1904.
BRODERICK, T. MONTEITH, Calumet and Hecla Mining Co., Calumet, Mich. Dec., 1921.
BROKAW, A. D., 157 Maplewood Ave., Maplewood, N. J. Dec., 1920.

BROWN, BARNUM, American Museum of Natural History, New York, N. Y. Dec., 1910.
BROWN, CHARLES WILSON, Brown University, Providence, R. I. Dec., 1908.
BROWN, JOHN STAFFORD, 520 West Third St., Joplin, Mo. Dec., 1922.
BROWN, THOMAS CLACHAR, Laurel Bank Farm, Fitchburg, Mass. Dec., 1915.
BRUCE, E. L., Queens University, Kingston, Ontario. Dec., 1920.
BRYAN, KIRK, U. S. Geological Survey, Washington, D. C. Dec., 1922.
BUCHER, W. H., University of Cincinnati, Cincinnati, Ohio. Dec., 1920.
BUDDINGTON, A. F., 124 Pyne Hall, Princeton, N. J. Dec., 1919.
BUEHLER, HENRY ANDREW, Rolla, Mo. Dec., 1909.
BURCHARD, E. F., U. S. Geological Survey, Washington, D. C. Dec., 1920.
BURLING, LANCASTER D., Vassar College, Poughkeepsie, N. Y. Dec., 1917.
BURWASH, EDWARD M. J., University of British Columbia, Vancouver, B. C. Dec., 1916.
BUTLER, BERT S., U. S. Geological Survey, Washington, D. C. Dec., 1912.
BUTLER, G. MONTAGUE, College of Mines, Tucson, Arizona. Dec., 1911.
BUTTS, CHARLES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
BUWALDA, J. P., Institute of Technology, Pasadena, Calif. Dec., 1920.
CADY, G. H., Illinois Geological Survey, Urbana, Ill. Dec., 1920.
CALHOUN, FRED HARVEY HALL, Clemson College, S. C. Dec., 1909.
CALKINS, FRANK C., U. S. Geological Survey, Washington, D. C. Dec., 1914.
CAMPBELL, HENRY D., Washington and Lee Univ., Lexington, Va. May, 1889.
CAMPBELL, MARIUS R., U. S. Geological Survey, Washington, D. C. Aug., 1892.
CAMSELL, CHARLES, Department of Mines, Ottawa, Canada. Dec., 1914.
CAPPS, STEPHEN R., JR., U. S. Geological Surv., Washington, D. C. Dec., 1911.
CARMAN, J. ERNEST, Ohio State University, Columbus, Ohio. Dec., 1917.
CARNEY, FRANK, Box 1031, Tulsa, Okla. Dec., 1908.
CASE, ERMINE C., University of Michigan, Ann Arbor, Mich. Dec., 1901.
CHADWICK, GEORGE H., 175 Bridge St., Catskill, N. Y. Dec., 1911.
CHAMBERLIN, ROLLIN T., University of Chicago, Chicago, Ill. Dec., 1913.
*CHAMBERLIN, T. C., Hyde Park Hotel, Hyde Park Blvd. and Harper Ave., Chicago, Ill.
CLAPP, CHARLES H., State University, Missoula, Mont. Dec., 1914.
CLAPP, FREDERICK G., 50 Church St., New York City. Dec., 1905.
CLARK, BRUCE L., Bacon Hall, Univ. of California, Berkeley, Calif. Dec., 1918.
CLARK, F. R., 723 Petroleum Bldg., Tulsa, Okla. Dec., 1919.
CLARK, W. O., Pahala, Kau, Hawaii. Dec., 1920.
CLARKE, EDWARD DE COURCY, University of Western Australia, Perth, Western Australia. Dec., 1924.
CLELAND, HERDMAN F., Williams College, Williamstown, Mass. Dec., 1905.
CLEMENTS, J. MORGAN, 20 Broad St., New York City. Dec., 1894.
COBB, COLLIER, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
COLEMAN, ARTHUR P., Toronto University, Toronto, Canada. Dec., 1896.
COLLIER, ARTHUR J., U. S. Geological Survey, Washington, D. C. June, 1902.
COLLINS, WILLIAM H., Geological Survey, Ottawa, Canada. Dec., 1921.
COLONY, ROY JED, Columbia University, New York City. Dec., 1924.
CONDIT, D. DALE, c/o Whitehall Petroleum Corp., Ltd., Bamboo Villa, Shillong, Assam, India. Dec., 1916.
COOK, CHARLES W., University of Michigan, Ann Arbor, Mich. Dec., 1915.

COOKE, C. WYTHE, U. S. Geological Survey, Washington, D. C. Dec., 1918.
CORBETT, CLIFTON S., c/o Nederlandsche Petroleum Maatschappij, Batavia, Java. Dec., 1925.
COSTE, EUGENE, 410 Royal Bank Bldg., Toronto, Canada. Dec., 1906.
COTTON, LEO ARTHUR, University of Sydney, Sydney, Australia. Dec., 1924.
CRAWFORD, RALPH DIXON, 1050 Tenth St., Boulder, Colo. Dec., 1916.
CROOK, ALJA R., State Museum of Natural History, Springfield, Ill. Dec., 1898.
CROSS, WHITMAN, 101 East Kirke St., Chevy Chase, Md. May, 1889.
CULVER, GARRY E., 310 Center Ave., Stevens Point, Wis. Dec., 1891.
CULVER, HAROLD E., State College, Pullman, Wash. Dec., 1925.
CUMINGS, EDGAR R., Indiana University, Bloomington, Ind. August, 1901.
CUSHMAN, J. A., Sharon, Mass. Dec., 1919.
DAKE, C. L., Missouri School of Mines, Rolla, Mo. Dec., 1920.
DALE, N. C., Hamilton College, Clinton, N. Y. Dec., 1920.
DALY, REGINALD A., Harvard University, Cambridge, Mass. Dec., 1905.
DANA, EDWARD SALISBURY, Yale University, New Haven, Conn. Dec., 1908.
*DARTON, NELSON H., U. S. Geological Survey, Washington, D. C.
DAVIS, E. F., 417 E. Randolph St., Glendale, Calif. Dec., 1920.
*DAVIS, WILLIAM M., 31 Hawthorne St., Cambridge, Mass.
DAY, ARTHUR LOUIS, Geophysical Laboratory, Washington, D. C. Dec., 1909.
DEAN, BASHFORD, Riverdale-on-Hudson, New York, N. Y. Dec., 1910.
DECKER, CHARLES ELIJAH, University of Oklahoma, Norman, Okla. Dec., 1924.
DE GOLYER, E. L., 65 Broadway, New York City. Dec., 1918.
DEUSSEN, ALEXANDER, 1917 Post-Dispatch Bldg., Houston, Texas. Dec., 1916.
DE WOLF, FRANK WILBRIDGE, 3502 Audubon Place, Houston, Texas. Dec., 1909.
DICKERSON, ROY E., 3015 Benvenue Ave., Berkeley, Calif. Dec., 1918.
*DILLER, JOSEPH S., U. S. Geological Survey, Washington, D. C.
D'INVILLIERS, EDWARD V., 121 North Broad St., Philadelphia, Pa. Dec., 1888.
DODGE, RICHARD E., Storrs, Conn. August, 1897.
DOLMAGE, VICTOR, 510 Pacific Bldg., Vancouver, B. C. Dec., 1922.
DRAKE, NOAH FIELDS, Fayetteville, Ark. Dec., 1898.
DRESSER, JOHN A., 701 Eastern Townships Bank Bldg., Montreal, Canada. Dec., 1906.
*DUMBLE, EDWIN T., 316 Pacific Bldg., Houston, Texas.
DUNBAR, C. O., Yale University, New Haven, Conn. Dec., 1920.
EAKLE, ARTHUR S., University of California, Berkeley, Calif. Dec., 1899.
ECKEL, EDWIN C., 1503 Decatur St. N. W., Washington, D. C. Dec., 1905.
EMERY, WILSON B., Casper, Wyoming. Dec., 1919.
*EMERSON, BENJAMIN K., Amherst, Mass.
EMMONS, WILLIAM H., Univ. of Minnesota, Minneapolis, Minn. Dec., 1912.
*FAIRCHILD, HERMAN L., University of Rochester, Rochester, N. Y.
FARRINGTON, OLIVER C., Field Museum of Natural History, Chicago, Ill. Dec., 1895.
FATH, A. E., Vacuum Oil Co., 61 Broadway, New York, N. Y. Dec., 1920.
FENNEMAN, NEVIN M., University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
FENNER, CLARENCE N., Geophysical Laboratory, Washington, D. C. Dec., 1911.
FERGUSON, H. G., U. S. Geological Survey, Washington, D. C. Dec., 1920.

FETTKE, CHARLES R., Carnegie Institute of Technology, Pittsburgh, Pa. Dec., 1924.
FISHER, CASSIUS ASA, 711 First Nat'l Bank Bldg., Denver, Colo. Dec., 1908.
FOERSTE, AUGUST F., 129 Wroe Ave., Dayton, Ohio. Dec., 1899.
FOHS, FERDINAND JULIUS, 51 East 42d St., New York, N. Y. Dec., 1923.
FORD, WILLIAM E., Sheffield Scientific School, New Haven, Conn. Dec., 1915.
FOYE, W. G., Wesleyan University, Middletown, Conn. Dec., 1919.
FULLER, MYRON L., 60 Main St., Brockton, Mass. Dec., 1898.
GALLOWAY, J. J., Columbia University, New York, N. Y. Dec., 1920.
GALPIN, SIDNEY L., 630 Park Ave., Ames, Iowa. Dec., 1917.
GANE, HENRY STEWART, Rural Del. No. 1, Santa Barbara, Calif. Dec., 1896.
GARDNER, JAMES H., 626 Kennedy Bldg., Tulsa, Okla. Dec., 1911.
GARDNER, JULIA A., U. S. Geological Survey, Washington, D. C. Dec., 1920.
GEORGE, RUSSELL D., University of Colorado, Boulder, Colo. Dec., 1906.
GIDLEY, JAMES WILLIAM, U. S. Nat'l Museum, Washington, D. C. Dec., 1922.
GILES, ALBERT W., University of Arkansas, Fayetteville, Ark. Dec., 1921.
GILL, ADAM CAPEN, Cornell University, Ithaca, N. Y. Dec., 1888.
GILMORE, CHARLES WHITNEY, U. S. National Museum, Washington, D. C. Dec., 1924.
GLENN, L. C., 2111 Garland Ave., Nashville, Tenn. June, 1900.
GOLDMAN, MARCUS I., U. S. Geol. Survey, Washington, D. C. Dec., 1916.
GOLDRING, WINIFRED, New York State Museum, Albany, N. Y. Dec., 1921.
GOLDTHWAIT, JAMES WALTER, Dartmouth College, Hanover, N. H. Dec., 1900.
GORDON, CHARLES H., University Library, University of Tennessee, Knoxville, Tenn. August, 1893.
GORDON, CLARENCE E., Massachusetts Agricultural College, Amherst, Mass. Dec., 1913.
GOULD, CHARLES N., 215 S. Webster, Norman, Okla. Dec., 1904.
GRABAU, AMADEUS W., Government University, Peking, China. Dec., 1898.
GRANGER, WALTER, American Museum of Natural History, New York, N. Y. Dec., 1911.
GRANT, ULYSSES SHERMAN, Northwestern Univ., Evanston, Ill. Dec., 1890.
GRASTY, JOHN SHARSHALL, Box 458, Charlottesville, Va. Dec., 1911.
GRATON, LOUIS C., Foxcroft House, Cambridge, 38, Mass. Dec., 1913.
GREGORY, HERBERT E., Yale University, New Haven, Conn. August, 1901.
GREENE, FRANK COOK, 1434 S. Cincinnati Ave., Tulsa, Okla. Dec., 1917.
GRIMSLEY, GEORGE P., 16 York Court, Baltimore, Md. August, 1895.
GROUT, FRANK F., University of Minnesota, Minneapolis, Minn. Dec., 1918.
GRUNER, JOHN W., University of Minnesota, Minneapolis, Minn. Dec., 1923.
GURLEY, WILLIAM F. E. R., University of Chicago, Chicago, Ill. Dec., 1914.
HALBERSTADT, BAIRD, Pottsville, Pa. Dec., 1909.
HANCE, J. H., Agricultural and Mechanical College, College Station, Texas. Dec., 1920.
HANCOCK, E. T. Dec., 1919.
HARDER, E. C., 1111 Harrison Bldg., Philadelphia, Pa. Dec., 1918.
HARES, C. J., 305 Franklin St., Denver, Colo. Dec., 1920.
HARRIS, GILBERT D., Cornell University, Ithaca, N. Y. Dec., 1903.
HARTNAGEL, CHRIS A., Education Bldg., Albany, N. Y. Dec., 1913.
HASTINGS, JOHN B., 8663 Cypress Ave., Southgate, Calif. May, 1889.

*HAWORTH, ERASMUS, University of Kansas, Lawrence, Kans.
HAY, OLIVER P., Carnegie Institution, Washington, D. C. Dec., 1921.
HAYES, ALBERT O., Natural History Museum, Saint John, N. B., Canada. Dec., 1919.
HEALD, K. C., 1161 Frick Bldg. Annex, Pittsburgh, Pa. Dec., 1920.
HENDERSON, JUNIUS, University of Colorado, Boulder, Colo. Dec., 1925.
HENNEN, RAY V., Transcontinental Oil Co., Tulsa, Okla. Dec., 1914.
HERSHEY, OSCAR H., Crocker Bldg., San Francisco, Calif. Dec., 1909.
HESS, FRANK L., U. S. Geological Survey, Washington, D. C. Dec., 1921.
HEWETT, DONNEL F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
HIGGINS, DANIEL F., 747 N. Jefferson Ave., Loveland, Colo. Dec., 1925.
HILL, J. M., 2671 Shasta Road, Berkeley, Calif. Dec., 1920.
*HILL, ROBERT T., Los Angeles Museum of Science & Arts, Los Angeles, Calif.
HILLS, THOMAS MCDOUGALL, Vassar College, Poughkeepsie, N. Y. Dec., 1924.
HINDS, HENRY, 1153 Laurel Ave., St. Paul, Minn. Dec., 1912.
HINTZE, FERDINAND FRIIS, 580 Corona St., Denver, Colo. Dec., 1917.
HOBBS, WILLIAM H., University of Michigan, Ann Arbor, Mich. August, 1891.
HOLDEN, ROY J., Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.
HOLLAND, WILLIAM JACOB, Carnegie Museum, Pittsburgh, Pa. Dec., 1910.
HOLLICK, ARTHUR, N. Y. Botanical Garden, New York, N. Y. August, 1898.
HOPKINS, O. B., Internat. Petr. Co., Ltd., 56 Church St., Toronto, Canada. Dec., 1919.
HOPKINS, THOMAS C., Syracuse University, Syracuse, N. Y. Dec., 1894.
HOTCHKISS, WILLIAM OTIS, College of Mines, Houghton, Mich. Dec., 1911.
HOWE, ERNEST, Litchfield, Conn. Dec., 1903.
HUBBARD, GEORGE D., Oberlin College, Oberlin, Ohio. Dec., 1914.
HUDSON, GEORGE H., Plattsburg Normal School, Plattsburg, N. Y. Dec., 1917.
HUME, GEORGE S., Geological Survey of Canada, Ottawa, Canada. Dec., 1923.
HUNT, WALTER F., University of Michigan, Ann Arbor, Mich. Dec., 1914.
HUNTINGTON, ELLSWORTH, Yale University, New Haven, Conn. Dec., 1906.
HUSSAKOF, LOUIS, 1537 50th St., Brooklyn, N. Y. Dec., 1910.
HYDE, J. E., Western Reserve University, Cleveland, Ohio. Dec., 1916.
JACKSON, ROBERT T., Peterborough, N. H. August, 1894.
JACOBS, ELBRIDGE C., University of Vermont, Burlington, Vt. Dec., 1921.
JEFFERSON, MARK S. W., Michigan State Normal College, Ypsilanti, Mich. Dec., 1904.
JEFFREY, EDWARD C., Harvard University, Cambridge, Mass. Dec., 1914.
JENKINS, OLAF P., Nederlandsche Koloniale Petroleum Maatshappy, Sluisburg, Weltevreden, Batavia, Java. Dec., 1921.
JOHANNSEN, ALBERT, University of Chicago, Chicago, Ill. Dec., 1908.
JOHNSON, B. L., U. S. Bureau of Mines, Washington, D. C. Dec., 1919.
JOHNSON, DOUGLAS WILSON, Columbia University, New York, N. Y. Dec., 1906.
JOHNSON, ROSWELL H., University of Pittsburgh, Pittsburgh, Pa. Dec., 1918.
JONAS, ANNA I., Room 4230, U. S. Geological Survey, Washington, D. C. Dec., 1922.
KATZ, FRANK JAMES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KAY, GEORGE FREDERICK, State Univ. of Iowa, Iowa City, Iowa. Dec., 1908.
KEITH, ARTHUR, U. S. Geological Survey, Washington, D. C. May, 1889.
*KEMP, JAMES F., Columbia University, New York, N. Y.

KEW, W. S. W., 1215 N. Howard St., Glendale, Calif. Dec., 1920.
KEYES, CHARLES ROLLIN, 944 Fifth St., Des Moines, Iowa. August, 1890.
KINDLE, EDWARD M., Victoria Memorial Museum, Ottawa, Canada. Dec., 1906.
KIRK, CHARLES T., Box 1592, Tulsa, Okla. Dec., 1915.
KIRK, EDWIN, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KNIGHT, CYRIL WORKMAN, Nipissing Mining Co., Ltd., Cobalt, Ontario, Canada. Dec., 1911.
KNOPF, ADOLPH, Yale Station New Haven, Conn. Dec., 1911.
KNOPF, ELEANORA BLISS, 105 East Rock Road, New Haven, Conn. Dec., 1919.
KNOWLTON, FRANK H., U. S. National Museum, Washington, D. C. May, 1889.
KRAUS, EDWARD HENRY, Univ. of Michigan, Ann Arbor, Mich. June, 1902.
KUMMEL, HENRY B., Trenton, N. J. Dec., 1895.
*KUNZ, GEORGE F., 401 Fifth Ave., New York, N. Y.
LAHEE, FREDERIC H., American Exchange Natl. Bank Bldg., Dallas, Texas. Dec., 1917.
LANDES, HENRY, University of Washington, University Station, Seattle, Wash. Dec., 1908.
LANE, ALFRED C., Tufts College, Mass. Dec., 1889.
LARSEN, ESPER S., JR., Geol. Mus., Harvard Univ., Cambridge, Mass. Dec., 1914.
LAWSON, ANDREW C., University of California, Berkeley, Calif. May, 1889.
LEE, WILLIS THOMAS, U. S. Geological Survey, Washington, D. C. Dec., 1903.
LEES, JAMES H., Iowa Geological Survey, Des Moines, Iowa. Dec., 1914.
LEIGHTON, MORRIS M., Illinois Geological Survey, Urbana, Ill. Dec., 1921.
LEITH, CHARLES K., University of Wisconsin, Madison, Wis. Dec., 1902.
LEONARD, ARTHUR G., State University of North Dakota, Grand Forks, N. Dak. Dec., 1901.
LEVERETT, FRANK, Ann Arbor, Mich. August, 1890.
LEWIS, JOSEPH VOLNEY, Rutgers University, New Brunswick, N. J. Dec., 1906.
LIBBEY, WILLIAM, Princeton University, Princeton, N. J. August, 1899.
LIDDLE, RALPH ALEXANDER, The Pure Oil Co., Mexia, Texas. Dec., 1921.
LINDGREN, WALDEMAR, Massachusetts Institute of Technology, Cambridge, Mass. August, 1890.
LISBOA, MIGUEL A. R., Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. Dec., 1913.
LITTLE, HOMER P., Clark University, Worcester, Mass. Dec., 1918.
LLOYD, E. R., First National Bank Bldg., Denver, Colo. Dec., 1919.
LOBECK, ARMIN KOHL, University of Wisconsin, Madison, Wis. Dec., 1924.
LOGAN, WILLIAM N., Indiana University, Bloomington, Ind. Dec., 1917.
LONGWELL, CHESTER R., Yale University, New Haven, Conn. Dec., 1923.
LOOMIS, FREDERICK BREWSTER, Amherst College, Amherst, Mass. Dec., 1909.
LOUDERBACK, GEORGE D., University of California, Berkeley, Calif. June, 1902.
LOUGHLIN, GERALD F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
LOW, ALBERT P., 154 McLaren St., Ottawa, Canada. Dec., 1905.
LULL, RICHARD SWANN, Yale University, New Haven, Conn. Dec., 1909.
LUPTON, CHARLES T., 611 17th St., Denver, Colo. Dec., 1916.
MCCALLIE, SAMUEL WASHINGTON, Atlanta, Ga. Dec., 1909.
MCCASKEY, HIRAM D., Central Point, Oregon. Dec., 1904.
MCCONNELL, RICHARD G., Rideau Club, Ottawa, Canada. May, 1889.

McCoy, Alex. W., 1020 Patterson Bldg., Denver, Colo. Dec., 1922.
MacDonald, Donald F., 16 Eastover Court, Louisville, Ky. Dec., 1915.
MacFarlane, James Rieman, Woodland Road, Pittsburgh, Pa. August, 1891.
MacKay, Bertram R., Geological Survey, Ottawa, Canada. Dec., 1922.
McKellar, Peter, Fort William, Ontario, Canada. August, 1890.
McLaughlin, Donald H., Rotch Bldg., Harvard University, Cambridge, Mass. Dec., 1922.
McLearn, Frank Harris, Geological Survey, Ottawa, Canada. Dec., 1923.
Mansfield, George R., 2067 Park Rd. N. W., Washington, D. C. Dec., 1909.
Marbut, Curtis F., Bureau of Soils, Washington, D. C. August, 1897.
Marsters, Vernon F., P. O. Box 561, Albuquerque, N. Mex. Aug., 1892.
Martin, George C., U. S. Geological Survey, Washington, D. C. June, 1902.
Martin, Lawrence, Library of Congress, Washington, D. C. Dec., 1909.
Mather, Kirtley F., Harvard Geological Museum, Cambridge, Mass., Dec., 1918.
Mathews, Edward B., Johns Hopkins University, Baltimore, Md. Aug., 1895.
Matson, George C., 408 Cosden Bldg., Tulsa, Okla. Dec., 1918.
Matthes, Francois E., U. S. Geol. Survey, Washington, D. C. Dec., 1914.
Matthew, W. D., American Museum of Natural History, New York, N. Y. Dec., 1903.
Maury, Carlotta J., Hastings-on-Hudson, N. Y. Dec., 1920.
Maynard, Thomas Poole, 181 Myrtle St., Atlanta, Ga. Dec., 1914.
Mead, Warren Judson, University of Wisconsin, Madison, Wis. Dec., 1916.
Mehl, Maurice G., University of Missouri, Columbia, Mo. Dec., 1922.
Meinzer, Oscar E., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Mendenhall, Walter C., U. S. Geol. Survey, Washington, D. C. June, 1902.
Merriam, John C., Carnegie Institution, Washington, D. C. August, 1895.
Merrill, George P., U. S. National Museum, Washington, D. C. Dec., 1888.
Mertie, John Beaver, Jr., 112 Park Ave., Takoma Park, D. C. Dec., 1923.
Merwin, Herbert E., Geophysical Laboratory, Washington, D. C. Dec., 1914.
Miller, Arthur M., State University of Kentucky, Lexington, Ky. Dec., 1897.
Miller, Benjamin L., Lehigh University, Bethlehem, Pa. Dec., 1904.
Miller, William John, University of California, Southern Branch, Los Angeles, Calif. Dec., 1909.
Miser, Hugh D., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Moffit, Fred Howard, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Moore, Elwood S., University of Toronto, Toronto, Canada. Dec., 1911.
Moore, Raymond C., University of Kansas, Lawrence, Kans. Dec., 1921.
Mook, Charles C., Metuchen, N. J. Dec., 1922.
Morse, William C., Agricultural and Mechanical College, Miss. Dec., 1925.
Munn, Malcolm John, 305 Cosden Bldg., Tulsa, Okla. Dec., 1909.
*Nason, Frank L., West Haven, Conn.
Nelson, W. A., Tennessee Geological Survey, Nashville, Tenn. Dec., 1920.
Newland, David Hale, Albany, N. Y. Dec., 1906.
Newsom, John F., Hobart Bldg., San Francisco, Calif. Dec., 1899.
Noble, Levi F., Valyermo, Calif. Dec., 1916.
Norton, William H., Cornell College, Mount Vernon, Iowa. Dec., 1895.
Norwood, Charles J., State University, Lexington, Ky. August, 1894.
O'Connell, Marjorie, 116-57 Farmers Blvd., St. Albans, L. I. Dec., 1919.

OGILVIE, IDA HELEN, Barnard College, Columbia University, New York, N. Y. Dec., 1906.
O'HARA, CLEOPHAS C., South Dakota School of Mines, Rapid City, S. Dak. Dec., 1904.
OHERN, DANIEL WEBSTER, 515 W. 14th St., Oklahoma City, Okla. Dec., 1911.
O'NEILL, J. J., McGill University, Montreal, Canada. Dec., 1920.
OSBORN, HENRY F., American Museum of Natural History, New York, N. Y. August, 1894.
OVERBECK, ROBERT M., c/o Caracoles Tin Co. of Bolivia, Casilla No. 674, La Paz, Bolivia, South America. Dec., 1921.
PACK, ROBERT W., Box 790, Beaumont, Texas. Dec., 1916.
PAIGE, SIDNEY, U. S. Geological Survey, Washington, D. C. Dec., 1911.
PALACHE, CHARLES, Harvard University, Cambridge, Mass. August, 1897.
PARKS, WILLIAM A., University of Toronto, Toronto, Canada. Dec., 1906.
*PATTON, HORACE B., 3111 West 36th Ave., Denver, Colo.
PENROSE, RICHARD A. F., JR., Bullitt Bldg., Philadelphia, Pa. May, 1889.
PERKINS, GEORGE H., University of Vermont, Burlington, Vt. June, 1902.
PERRY, JOSEPH H., 276 Highland St., Worcester, Mass. Dec., 1888.
PHALEN, WILLIAM C., Drawersland 2, Syracuse, N. Y. Dec., 1912.
PHILLIPS, ALEXANDER H., Princeton University, Princeton, N. J. Dec., 1914.
PLUMMER, FREDERICK B., 504 Colquitt Bldg., Houston, Texas. Dec., 1925.
POGUE, JOSEPH E., 42 West 12th St., New York City. Dec., 1911.
POWERS, SIDNEY, Amerada Petr. Corp., Tulsa, Okla. Dec., 1920.
PRATT, JOSEPH H., North Carolina Geol. Survey, Chapel Hill, N. C. Dec., 1898.
PRATT, W. E., Humble Oil and Refining Co., Houston, Texas. Dec., 1920.
PRICE, WILLIAM A., 539 West Bldg., Houston, Texas. Dec., 1916.
PRINDLE, LOUIS M., U. S. Geological Survey, Washington, D. C. Dec., 1912.
PROUTY, WILLIAM F., Univ. of North Carolina, Chapel Hill, N. C. Dec., 1911.
QUIRKE, TERENCE T., University of Illinois, Urbana, Ill. Dec., 1921.
RANSOME, FREDERICK L., University Station, Tucson, Ariz. August, 1895.
RAYMOND, PERCY EDWARD, Museum of Comparative Zoology, Cambridge, Mass. Dec., 1907.
REBER, LOUIS E., Box 1096, Jerome, Ariz. Dec., 1923.
REEDS, CHESTER A., American Museum of Natural History, New York, N. Y. Dec., 1913.
REESIDE, JOHN B., JR., U. S. Geological Survey, Hyattsville, Md. Dec., 1921.
REEVES, FRANK, U. S. Geological Survey, Washington, D. C. Dec., 1924.
REGER, DAVID B., Box 816, Morgantown, W. Va. Dec., 1918.
REID, HARRY FIELDING, Johns Hopkins University, Baltimore, Md. Dec., 1892.
REINECKE, LEOPOLD, P. O. Box 2682, Johannesburg, Transvaal, South Africa. Dec., 1916.
RICE, WILLIAM NORTH, Wesleyan University, Middletown, Conn. Aug., 1890.
RICH, JOHN LYON, Box 3, Ottawa, Kans. Dec., 1912.
RICHARDS, R. W., U. S. Geological Survey, Washington, D. C. Dec., 1920.
RICHARDSON, CHARLES H., Syracuse University, Syracuse, N. Y. Dec., 1890.
RICHARDSON, GEORGE B., U. S. Geol. Survey, Washington, D. C. Dec., 1908.
RIES, HEINRICH, Cornell University, Ithaca, N. Y. Dec., 1893.
RIGGS, ELMER S., Field Museum of Natural History, Chicago, Ill. Dec., 1911.
RODDY, H. J., State Normal School, Millersville, Pa. Dec., 1919.

ROGERS, AUSTIN F., Stanford University, Calif. Dec., 1918.
ROSE, BRUCE, Department of Geology, Queens University, Kingston, Ontario, Canada. Dec., 1916.
RUEDEMANN, RUDOLF, Albany, N. Y. Dec., 1905.
RUTLEDGE, JOHN JOSEPH, State Bureau of Mines, 22 Light St., Baltimore, Md. Dec., 1911.
SALES, RENO H., Anaconda Copper Mining Co., Butte, Mont. Dec., 1916.
SAMPSON, EDWARD, U. S. Geological Survey, Washington, D. C. Dec., 1924.
SARDESON, FREDERICK W., 414 Harvard St., S. E. Minneapolis, Minn. Dec., 1892.
SAYLES, ROBERT WILCOX, Harvard University, Chestnut Hill, Mass. Dec., 1917.
SAVAGE, THOMAS EDMUND, University of Illinois, Urbana, Ill. Dec., 1907.
SCHALLER, WALDEMAR T., U. S. Geol. Survey, Washington, D. C. Dec., 1918.
SCHOFIELD, S. J., University of British Columbia, Vancouver, B. C. Dec., 1918.
SCHRADER, FRANK C., U. S. Geological Survey, Washington, D. C. Aug., 1901.
SCHUCHERT, CHARLES, Yale University, New Haven, Conn. August, 1895.
SCHULTZ, ALFRED R., Hudson, Wis. Dec., 1912.
SCHWARTZ, GEORGE M., Univ. of Minnesota, Minneapolis, Minn. Dec., 1923.
SCOTT, IRVING D., University of Michigan, Ann Arbor, Mich. Dec., 1923.
SCOTT, WILLIAM B., Princeton University, Princeton, N. J. August, 1892.
SEAMAN, ARTHUR E., Michigan College of Mines, Houghton, Mich. Dec., 1904.
SEARS, JULIAN DUCKER, 209 E. Underwood St., Chevy Chase, Md. Dec., 1924.
SELLARDS, ELIAS H., University of Texas, Austin, Texas. Dec., 1905.
SEMMES, DOUGLAS R., Apartado postal, 150, Tampico, Tamaulipas, Mexico. Dec., 1921.
SHALER, MILLARD K., 66 Rue Des Colonies, Brussels, Belgium. Dec., 1914.
SHATTUCK, GEORGE BURBANK, Mt. Royal Station, Baltimore, Md. Aug., 1899.
SHAW, EUGENE W., 170 Broadway, New York, N. Y. Dec., 1912.
SHEDD, SOLON, Box 1888, Stanford University, Calif. Dec., 1904.
SHEPARD, EDWARD M., 1403 Benton Ave., Springfield, Mo. August, 1901.
SHIMEK, BOHUMIL, University of Iowa, Iowa City, Iowa. Dec., 1904.
SHIMER, HERVEY WOODBURN, Massachusetts Institute of Technology, Cambridge, Mass. Dec., 1910.
SHULER, E. W., South Methodist University, Dallas, Texas. Dec., 1920.
SIEBENTHAL, CLAUDE E., U. S. Geol. Survey, Washington, D. C. Dec., 1912.
*SIMONDS, FREDERICK W., University of Texas, Austin, Texas.
SIMPSON, HOWARD E., University of North Dakota, Grand Forks, N. Dak. Dec., 1923.
SINCLAIR, WILLIAM JOHN, Princeton University, Princeton, N. J. Dec., 1906.
SINGEWALD, JOSEPH T., Johns Hopkins University, Baltimore, Md. Dec., 1911.
SLOAN, EARLE, Charleston, S. C. Dec., 1908.
SMITH, BURNETT, Syracuse University, Skaneateles, N. Y. Dec., 1911.
SMITH, CARL, Agra, Okla. Dec., 1912.
*SMITH, EUGENE A., University of Alabama, University, Ala.
SMITH, GEORGE OTIS, U. S. Geological Survey, Washington, D. C. Aug., 1897.
SMITH, PHILIP S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
SMITH, RICHARD A., Biological Survey of Michigan, Lansing, Mich. Dec., 1921.
SMITH, STANLEY, University of Bristol, Bristol, England. Dec., 1922.
SMITH, WARREN DU PRÉ, University of Oregon, Eugene, Ore. Dec., 1909.

SMITH, W. S. TANGIER, 640 Tennyson Ave., Palo Alto, Calif. June, 1902.
SMYTH, CHARLES H., JR., Princeton University, Princeton, N. J. Aug., 1892.
SMYTH, HENRY L., Harvard University, Cambridge, Mass. August, 1894.
SOMERS, R. E., Oil and Gas Bldg., University of Pittsburgh, Pittsburgh, Pa. Dec., 1919.
SOPER, EDGAR K., 1401 Cowper St., Palo Alto, Calif. Dec., 1918.
SOSMAN, R. B., Geophysical Laboratory, Washington, D. C. Dec., 1920.
SPEIGHT, ROBERT, Canterbury College, Christ Church, New Zealand. Dec., 1916.
SPENCER, ARTHUR COE, U. S. Geological Survey, Washington, D. C. Dec., 1896.
SPIEKER, EDMUND MAUTE, State University of Ohio, Columbus, Ohio. Dec., 1924.
SPRINGER, FRANK, U. S. National Museum, Washington, D. C. Dec., 1911.
SPURR, JOSIAH E., c/o Engineering and Mining Journal, 10th Ave. and 36th St., New York, N. Y. Dec., 1894.
STANLEY-BROWN, JOSEPH, 26 Exchange Place, New York, N. Y. August, 1892.
STANTON, TIMOTHY W., U. S. Nat'l Museum, Washington, D. C. August, 1891.
STAUFFER, CLINTON R., Univ. of Minnesota, Minneapolis, Minn. Dec., 1911.
STEBINGER, EUGENE, JR., 719 Edificio Banco Boston, Buenos Aires, Argentina. Dec., 1916.
STEIDTMANN, EDWARD, 13 White St., Lexington, Va. Dec., 1916.
STEPHENSON, LLOYD W., U. S. Geol. Survey, Washington, D. C. Dec., 1911.
STOLLER, JAMES HOUGH, Union College, Schenectady, N. Y. Dec., 1917.
STONE, RALPH WALTER, State Geological Survey, Harrisburg, Pa. Dec., 1912.
STOSE, GEORGE WILLIS, U. S. Geological Survey, Washington, D. C. Dec., 1908.
STOUT, WILBER, Geological Survey of Ohio, Columbus, Ohio. Dec., 1918.
SUSSMILCH, CARL ADOLPH, Technical College, Newcastle, Australia. Dec., 1925.
SWARTZ, CHARLES K., Johns Hopkins University, Baltimore, Md. Dec., 1908.
TABER, STEPHEN, University of South Carolina, Columbia, S. C. Dec., 1914.
TAFF, JOSEPH A., 629 Cooper St., Palo Alto, Calif. August, 1895.
TALBOT, MIGNON, Mount Holyoke College, South Hadley, Mass. Dec., 1913.
TALMAGE, JAMES E., Durham House, Edge Lane, Liverpool, England. Dec., 1897.
TARR, WILLIAM ARTHUR, 1316 Ross St., Columbia, Mo. Dec., 1917.
TAYLOR, FRANK B., 420 Downing Ave., Fort Wayne, Ind. Dec., 1895.
THIEL, GEORGE A., University of Minnesota, Minneapolis, Minn. Dec., 1925.
THOM, WILLIAM TAYLOR, JR., U. S. Geological Survey, Washington, D. C. Dec., 1924.
THOMAS, ABRAM O., University of Iowa, Iowa City, Iowa. Dec., 1921.
THORPE, MALCOLM R., 1463 Yale Station, New Haven, Conn. Dec., 1923.
THWAITES, FREDRIK T., Science Hall, Madison, Wis. Dec., 1925.
TILTON, J. L., Morgantown, W. Va. Dec., 1920.
TOMLINSON, CHARLES WELDON, 1610 Bixby Ave., Ardmore, Okla. Dec., 1917.
TROWBRIDGE, ARTHUR C., State Univ. of Iowa, Iowa City, Iowa. Dec., 1913.
TROXELL, EDWARD L., Trinity College, Hartford, Conn. Dec., 1923.
*TURNER, HENRY W., Mills Bldg., San Francisco, Calif.
TWENHOFEL, WILLIAM H., University of Wisconsin, Madison, Wis. Dec., 1913.
TWITCHELL, MAYVILLE W., State Geological Survey, Trenton, N. J. Dec., 1911.
TYRRELL, JOSEPH B., Confederation Life Bldg., Toronto, Canada. May, 1889.

UDDEN, JOHAN A., University of Texas, Austin, Texas. August, 1897.
UGLOW, WILLIAM L., University of British Columbia, Vancouver, B. C. Dec., 1922.
ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C. Dec., 1903.
UMPLEBY, JOSEPH B., University of Oklahoma, Norman, Okla. Dec., 1913.
*UPHAM, WARREN, Minnesota Historical Society, Saint Paul, Minn.
VAN HORN, F. R., Case School of Applied Science, Cleveland, Ohio. Dec., 1898.
VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo. Dec., 1917.
VAUGHAN, T. WAYLAND, Scripps Institution, La Jolla, Calif. August, 1896.
VEATCH, ARTHUR CLIFFORD, 7 Central Drive, Port Washington, N. Y. Dec., 1906.
VISHER, STEPHEN S., 817 E. Second St., Bloomington, Ind. Dec., 1923.
WADE, BRUCE, State Geological Survey, Nashville, Tenn. Dec., 1920.
*WALCOTT, CHARLES D., Smithsonian Institution, Washington, D. C.
WALKER, THOMAS L., University of Toronto, Toronto, Canada. Dec., 1903.
WARD, FREEMAN, University of South Dakota, Vermilion, S. Dak. Dec., 1925.
WARD, LEONARD KEITH, Department of Mines, Adelaide, South Australia. Dec., 1924.
WARING, GERALD A., Margay Oil Corp., Box 2103, Tulsa, Okla. Dec., 1921.
WARREN, CHARLES H., Yale University, New Haven, Conn. Dec., 1901.
WASHBURNE, C. W., 2 Rector St., New York, N. Y. Dec., 1919.
WASHINGTON, HENRY S., Geophysical Laboratory, Washington, D. C. Aug., 1896.
WEAVER, CHARLES E., University of Washington, Seattle, Wash. Dec., 1913.
WEED, WALTER H., Post Road, Searsdale, N. Y. May, 1889.
WEGEMANN, CARROLL H., Pan American Exploration Co., 120 Broadway, New York, N. Y. Dec., 1912.
WEIDMAN, SAMUEL, 814 Monett St., Norman, Okla. Dec., 1903.
WELLER, STUART, University of Chicago, Chicago, Ill. June, 1900.
WELLS, ROGER C., U. S. Geological Survey, Washington, D. C. Dec., 1921.
WENTWORTH, CHESTER K., U. S. Geological Survey, Washington, D. C. Dec., 1923.
WESTGATE, LEWIS G., 124 Oak Hill Ave., Delaware, Ohio. August, 1894.
WHERRY, EDGAR T., Bureau of Chemistry, Washington, D. C. Dec., 1915.
WHITE, DAVID, U. S. National Museum, Washington, D. C. May, 1889.
*WHITE, ISRAEL C., Morgantown, W. Va.
WHITLOCK, H. P., Amer. Museum of Natural History, N. Y. City. Dec., 1920.
WHITNEY, FRANCIS L., University of Texas, Austin, Texas. Dec., 1923.
WIELAND, GEORGE REBER, Yale University, New Haven, Conn. Dec., 1910.
WILDER, FRANK A., North Holston, Smyth County, Va. Dec., 1905.
*WILLIAMS, EDWARD H., JR., Woodstock, Vt.
WILLIAMS, IRA A., 821 Spalding Bldg., Portland, Ore. Dec., 1905.
WILLIAMS, MERTON YARWOOD, Univ. of British Columbia, Vancouver, B. C. Dec., 1916.
WILLIS, BAILEY, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1889.
WILSON, ALFRED W. G., Department of Mines, Ottawa, Canada. June, 1902.
WILSON, MORLEY EVANS, Geological Survey, Ottawa, Canada. Dec., 1916.
WINCHELL, ALEXANDER N., University of Wisconsin, Madison, Wis. Aug., 1901.

*WINSLOW, ARTHUR, 131 State St., Boston, Mass.
WOLFF, JOHN E., 360 S. Grand Ave., Pasadena, Calif. Dec., 1889.
WOOD, HARRY OSCAR, Mt. Wilson Observatory, Pasadena, Calif. Dec., 1922.
WOODMAN, JOSEPH E., New York University, New York, N. Y. Dec., 1905.
WOODRING, WENDELL P., U. S. Geol. Survey, Washington, D. C. Dec., 1921.
WOODRUFF, E. G., 1611 S. Detroit St., Tulsa, Okla. Dec., 1922.
WOOLNOUGH, WALTER GEORGE, "Callabonna," Florence St., Killara, New South Wales. Dec., 1924.
WRATHER, WILLIAM E., 6044 Bryan Parkway, Dallas, Texas. Dec., 1923.
WRIGHT, CHARLES WILL, 28 Vie del Parliamento, Rome, Italy. Dec., 1909.
WRIGHT, FREDERIC E., Geophysical Laboratory, Washington, D. C. Dec., 1903.

CORRESPONDENTS DECEASED

CAPELLINI, GIOVANNI. Died 1924.
CREDNER, HERMAN. Died July 22, 1913.
DE STEFANI, CARLO. Died Dec. 12, 1924.
GEIKIE, SIR ARCHIBALD. Died Nov., 1924.
MICHEL-LÉVY, A. Died September, 1911.
ROSENBUSCH, H. Died January 20, 1914.
SUESS, EDWARD. Died April 20, 1914.
TEALL, SIR J. J. H. Died July 2, 1924.
TSCHERNYSCHEW, TH. Died Jan. 15, 1914.
ZIRKEL, FERDINAND. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*ASHBURNER, CHAS. A. Died Dec. 24, 1889.
BARLOW, ALFRED E. Died May 28, 1914.
BARRELL, JOSEPH. Died May 4, 1919.
BEECHER, CHARLES E. Died Feb. 14, 1904.
*BECKER, GEORGE F. Died April 20, 1919.
BELL, ROBERT. Died June 18, 1917.
BICKMORE, ALBERT S. Died Aug. 12, 1914.
BLAKE, WM. PHIPPS. Died May 21, 1910.
BOWMAN, AMOS. Died June 18, 1894.
*BRANNER, JOHN C. Died March 1, 1922.
BROOKS, ALFRED H. Died Nov. 22, 1924.
BROWN, AMOS P. Died Oct. 9, 1917.
BUCKLEY, ERNEST R. Died Jan. 19, 1912.
CAIRNES, D. D. Died June 14, 1917.
*CALVIN, SAMUEL. Died April 17, 1911.
CARPENTER, FRANK R. Died April 1, 1910.
CASTILLO, ANTONIO DEL. Died Oct. 28, 1895.
CHAPIN, J. H. Died March 14, 1892.
CLARK, WILLIAM B. Died July 27, 1917.
CLARKE, JOHN MASON. Died May 29, 1925.
*CLAYPOLE, EDWARD W. Died Aug. 17, 1901.
*COMSTOCK, THEO. B. Died July 26, 1915.
COOK, GEORGE H. Died Sept. 22, 1889.
*COPE, EDWARD D. Died April 12, 1897.
COX, GEORGE H. Died August 20, 1922
*CROSBY, WILLIAM O. Died Dec. 31, 1925.
*CUSHING, H. P. Died April 14, 1921.
*DANA, JAMES D. Died April 14, 1895.
DAVIS, CHARLES A. Died April 9, 1916.
DAWSON, GEORGE M. Died March 2, 1901.
DAWSON, SIR J. WM. Died Nov. 19, 1899.
DAY, DAVID T. Died April 15, 1925.
DERBY, ORVILLE A. Died Nov. 27, 1915.
DRYSDALE, CHAS. W. Died July 10, 1917.
DUTTON, CLARENCE E. Died Jan. 4, 1912.
*DWIGHT, WM. B. Died Aug. 29, 1906.
EASTMAN, CHAS. R. Died Sept. 27, 1918.
*ELDRIDGE, GEORGE H. Died June 29, 1905.
*EMMONS, SAMUEL F. Died March 28, 1911.
FONTAINE, WM. M. Died April 30, 1913.
*FOOTE, ALBERT E. Died October 10, 1895.
*FRAZER, PERSIFOR. Died April 7, 1909.
*FULLER, HOMER T. Died Aug. 14, 1908.
*GILBERT, GROVE K. Died May 1, 1918.
GIROUX, N. J. Died Nov. 30, 1891.
HAGUE, ARNOLD. Died May 14, 1917.
*HALL, CHRISTOPHER W. Died May 10, 1911.
*HALL, JAMES. Died August 7, 1898.
HARRISON, JOHN B. Died Feb. 8, 1926.
HATCHER, JOHN B. Died July 3, 1904.
*HAY, ROBERT. Died December 14, 1895.
HAYES, C. WILLARD. Died Feb. 9, 1916.
*HEILPRIN, ANGELO. Died July 17, 1907.
HICE, RICHARD R. Died March 27, 1925.
HILGARD, EUGENE W. Died Jan. 8, 1916.
HILL, FRANK A. Died July 13, 1915.
HILLS, RICHARD C. Died Aug. 14, 1923.
*HITCHCOCK, CHAS. H. Died Nov. 7, 1919.
*HOLBROOK, LEVI. Died July 26, 1922.
*HOLMES, JOSEPH A. Died July 13, 1915.
*HONEYMAN, DAVID. Died Oct. 17, 1889.
*HOVEY, EDMUND O. Died Sept. 27, 1924.
*HOVEY, HORACE C. Died July 27, 1914.
*HOWELL, EDWIN E. Died April 16, 1911.
HUNT, THOMAS S. Died Feb. 12, 1892.
*HYATT, ALPHEUS. Died Jan. 15, 1902.
IDDINGS, J. P. Died Sept. 8, 1920.
IRVING, JOHN D. Died July 26, 1918.
JACKSON, THOMAS M. Died Feb. 3, 1912.
*JAMES, JOSEPH F. Died March 29, 1897.
JULIEN, ALEXIS A. Died May 7, 1919.
KENNEDY, WILLIAM. Died Feb. 23, 1926.
KNIGHT, WILBUR C. Died July 28, 1903.
LACOE, RALPH D. Died February 5, 1901.
LAFLAMME, J. C. K. Died July 6, 1910.
LAMBE, L. M. Died March 12, 1919.
LANGTON, DANIEL W. Died June 21, 1909.
*LE CONTE, JOSEPH. Died July 6, 1901.
*LESLEY, J. PETER. Died June 2, 1903.
LOUGHRIDGE, ROBT. H. Died July 1, 1917.
MCCALLEY, HENRY. Died Nov. 20, 1904
*MCGEE, W J. Died Sept. 4, 1912.
MCINNES, WILLIAM. Died March 10, 1925.
MARCY, OLIVER. Died March 19, 1899.
MARSH, OTHNIEL C. Died March 18, 1899.
MELL, P. H. Died October 12, 1918.
*MERRILL, FRED. J. H. Died Nov. 29, 1916.
MILLER, WILLET G. Died Feb. 4, 1925.
MILLS, JAMES E. Died July 25, 1901.
*NASON, HENRY B. Died Jan. 17, 1895.
*NEFF, PETER. Died May 11, 1903.
*NEWBERRY, JOHN S. Died Dec. 7, 1892.
NILES, WILLIAM H. Died Sept. 12, 1910.

*Orton, Edward. Died October 16, 1899.
*Osborn, Amos O. Died March, 1911.
*Owen, Richard. Died March 24, 1890.
Peck, Frederick B. Died Nov. 2, 1925.
Penfield, Samuel L. Died Aug. 14, 1903.
Penhallow, David P. Died Oct. 20, 1910.
Pirsson, L. V. Died Dec. 8, 1919.
*Platt, Franklin. Died July 24, 1900.
Pettee, William H. Died May 26, 1904.
*Powell, John W. Died Sept. 23, 1902.
*Prosser, Chas. S. Died Sept. 41, 1916.
*Pumpelly, Raphael. Died August, 1923.
Purdue, A. H. Died Dec. 12, 1917.
Robinson, Henry H. Died Oct. 20, 1925.
Rogers, G. S. Died Nov. 18, 1919.
*Russell, Israel C. Died May 1, 1906.
*Safford, James M. Died July 3, 1907.
Saint John, O. H. Died July 17, 1921.
*Salisbury, Rollin D. Died Aug. 15, 1922.
*Schaeffer, Charles. Died Nov. 23, 1903.
Seely, H. M. Died May 4, 1917.
Sesa. J. C. da Costa. Died June 20, 1919.
*Shaler, Nathaniel S. Died Apr. 10, 1906.
*Smock, John C. Died May, 1926.
*Spencer, J. W. Died October 9, 1921.
*Stevenson, John J. Died Aug. 10, 1924.
Sutton, William J. Died May 9, 1915.
Tarr, Ralph S. Died March 21, 1912.
Tight, William G. Died Jan. 15, 1910.
*Todd, James E. Died October 29, 1922.
*Van Hise, C. R. Died Nov. 19, 1918.
Van Ingen, Gilbert. Died July 7, 1925.
*Vogdes, Anthony W. Died Feb. 8, 1923.
Wachsmuth, Chas. Died Feb. 7, 1896.
Wadsworth, M. E. Died April 21, 1921.
Watson, Thomas L. Died Nov. 10, 1924.
Weston, Thomas C. Died July 20, 1910.
White, Theodore G. Died July 7, 1901.
*Whitfield, Robt. P. Died April 6, 1910.
*Williams, George H. Died July 12, 1894.
*Williams, J. Francis. Died Nov. 9, 1891.
*Williams, H. S. Died July 31, 1918.
Wilmott, Arthur B. Died May 8, 1914.
*Winchell, Alex. Died Feb. 19, 1891.
*Winchell, H. V. Died July 28, 1923.
*Winchell, Newton H. Died May 1, 1914.
Woodward, Robt. S. Died June 29, 1924.
Woodworth, Jay B. Died Aug. 4, 1925.
Wright, Albert A. Died April 2, 1905.
*Wright, G. F. Died April 20, 1921.
Yeates, William S. Died Feb. 19, 1908.

Summary

Correspondents	19
Original Fellows	21
Elected Fellows	479
Membership	519
Deceased Correspondents	10
Deceased Fellows	144

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PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL MEETING OF THE CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT BERKELEY, CALIFORNIA, FEBRUARY 20 AND 21, 1925.

JOHN P. BUWALDA, *Secretary*

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SESSIONS OF FEBRUARY 20 AND 21, 1925

The twenty-fourth annual meeting of the Cordilleran Section of the Geological Society of America was held at Bacon Hall, University of California, Berkeley, on Friday and Saturday, February 20 and 21, 1925.

ELECTION OF OFFICERS

At a brief business meeting, held early in the afternoon of February 21, a Nominating Committee appointed by the Chairman, W. D. Smith, proposed the following officers for the year 1926:

Chairman, ELIOT BLACKWELDER
Secretary, JOHN P. BUWALDA
Councilor, WILLIAM J. MILLER

The nominees were subsequently elected in a mail ballot conducted by the Secretary.

PRESENTATION OF PAPERS

The first session of the meetings was called to order at 2 p. m., on February 20, by Chairman W. D. Smith.

The following papers were offered in the order indicated:

EXTENSIVE PREGLACIAL OXIDATION OF LEAD DEPOSITS IN NORTHEASTERN WASHINGTON

BY OLAF P. JENKINS

(*Abstract*)

The rich lead ore chimneys of the Electric Point and Gladstone mines are quite thoroughly oxidized as deep as they have been mined. The lowest level reached is 800 feet below the surface. The primary ore mineral is galena and its oxidized products are anglesite and cerussite. Soft limonite, limonitic clay dikes, and dolomitic sand, together with dolomite-breccia, make up the gangue. The limonite is thought to be derived from siderite rather than pyrite. The oxidation of the limonite evidently made the whole mass of each ore chimney or pipe extremely porous. The porous condition of the chimneys, their vertical attitude, and the fact that ground water level has not yet been reached in mining give an ideal condition to cause oxidation. Deep oxidation is generally wanting in the region, however, for glacial action has removed most preglacial surface altered deposits. This is a special case of preserved preglacial oxidation. The proof of its earlier age lies in the fact that limonitic clay dikes, which ramify through the ore chimneys and were formed with the general oxidation, are found beveled off at the surface with glacial till overlying them unconformably. Probably the oxidation was going on during the Tertiary and its products were preserved over the Glacial period, but renewed in recent times.

Read by title in the absence of the author.

VOLTAITE FROM JEROME, ARIZONA

BY CHARLES A. ANDERSON

(*Abstract*)

Good crystals of voltaite have been found in the upper levels of the United Verde Mine, Jerome, Arizona. They are thought to have been formed by ascending sulphur vapors from burning sulfide ore.

EVIDENCE FURNISHED BY THE EARTHQUAKE OF JUNE 26, 1924, FOR A SHARPLY BOUNDED AND VERY RIGID CORE IN THE EARTH

BY JAMES B MACELWANE

(*Abstract*)

A very violent earthquake occurred in the South Pacific Ocean, beyond New Zealand, June 28, 1924. This position of the epicenter fortunately placed a number of seismographic stations at critical distances for the observation of rays through the core of the earth. Good copies or the loan of original seismograms were asked and obtained from a large number of important stations throughout the world. The energy of the direct longitudinal and transverse waves arriving at the nearer stations up to Honolulu and Rio de Janeiro was very great. Beyond this the amplitude of the longitudinal wave dropped to

almost nothing and finally disappeared. But simultaneously with the drop in energy of the first, a second longitudinal group of very slight energy appeared. It was too small to register at Saint Louis, but appeared at Chicago. At Toronto it was still fairly small, but at Ottawa, two degrees farther away, it was very large indeed. From there to the antipodes it is a conspicuous group. This shadow zone, with its sharp boundaries, can be explained only as a lens effect of a sharply bounded core. Transverse waves transmitted by the core seem to be present on the records of most stations that are favorably situated from Saint Louis, Chicago, and Ottawa onward. Their speed is such as to indicate an exceedingly rigid core.

FAULT TOPOGRAPHY IN HAWAII

BY NORMAN E. A. HINDS

(*Abstract*)

Faulting, which is one of the principal agents modifying the relief of lava domes, has produced notable topographic features in Hawaii. On Mauna Loa and Kilauea are gaping fissures, from some of which small quantities of lava or even extensive lava flows have been emitted. Low fault-scarps, representing relatively small amounts of displacement, are common on the flanks of the young domes. At the summits of Mauna Loa and Kilauea are small sinks which have been developed by engulfment caused by the withdrawal of lava from below. On east and west Oahu and on Kauai are much larger sinks, which have been formed by the downfaulting of major sections of these volcanoes. The depressions may possibly have been enlarged from small summit sinks after the close of the principal eruptive period. At the summit of east Maui is a great faulted depression 7.8 miles in length by 2.3 miles in width; the walls are slightly dissected, steeply sloping scarps from 2,000 to 2,500 feet high. Two fault-gaps, each more than a mile in width, breach the walls of the depression. This structure has been explained as a volcanic sink and as a volcanic rent.

The high dissected cliffs, forming considerable sections of the coasts of the Kohala section of Hawaii, east Molokai, northwestern Kauai, and Niihau, have been ascribed to faulting, which has caused the subsidence below sea-level of large sections of these domes. In all of the cases cited the present cliffs have apparently retreated for some distance from the line of dislocation under the powerful attack of the ocean waves. Further investigation is necessary to determine whether the Kohala and Niihau cliffs especially were originally developed by faulting or whether they are merely the result of long-continued wave-attack.

The aberrant, north-south course of the principal river of western Kauai, which transgresses the normal radial direction of the drainage of that section of the island, is believed to have been determined by a line or zone of faulting.

Illustrated by lantern slides. Discussed by Messrs. W. M. Davis and H. O. Wood.

GEOMORPHOGENY OF THE BERKELEY HILLS BETWEEN THE CITY OF BERKELEY AND SAN PABLO BAY

BY JAMES P. FOX

(*Abstract*)

North of the University of California the western slope of the Berkeley Hills bevels quite smoothly a thick series of disordered Franciscan (Jurassic?) schists, sandstones, and serpentines. East of the crest of the slope the Franciscan rocks are bounded by soft folded Orindan (Pliocene) strata. The general strike of the formations is northwestward and oblique to the face of the hills; consequently the Campan (Pliocene), Franciscan, and Orindan (Pliocene) formations, of greatly different degrees of resistence, form the face. The physiographic history of the region seems to be:

(1) *Peneplanation and uplift.* After a long period of erosion, which reduced the region to a peneplane, warping and faulting occurred. A gentle sloping lowland was produced to the west, on which Berkeley and Albany lie. It passes eastward into a flexure with ten-degree slope which rises to the crest of the front ridge. Beyond, the reconstructed surface presumably flattened and presumably passed through the ridge crests to the east.

(2) *Dissection in consequence of initial uplift.* Dissection on the west slope is slight in consequence of the new cycle introduced. Landsliding is common and alluvial fans are being formed on the lowland. In the soft Pliocene strata east of the crest an old stream, Wildcat Creek, flowing northward at a small angle to the strike of the strata, was revived and cut a valley of notable size.

(3) *Baseleveling and further uplifting.* Farther north, extending southeastward from the shore of San Pablo Bay, is the rather smooth Sobrante surface. It was developed on Pliocene strata by lateral planation of San Pablo Creek while Wildcat Canyon was being sculptured.

(4) *Dissection.* Renewed uplift occurred, the Sobrante surface was submaturely dissected, and Wildcat Canyon and San Pablo Valley were further deepened to their present form.

Read from manuscript. Discussed by Messrs. W. M. Davis, B. L. Clark, and J. P. Buwalda.

SOME PHYSIOGRAPHIC EVIDENCE OF HORIZONTAL DISPLACEMENT ON A PORTION OF THE HAYWARD FAULT

BY RICHARD J. RUSSELL

(*Abstract*)

The portion of the Hayward fault studied is situated some twenty to thirty miles east-southeast of San Francisco, California. In a distance of nine miles all stream courses are offset, so that their lower portions on the Bay Plain are now northwest of their extensions in the Berkeley Hills. The zonal nature of the fault is brought out by successive offsets along single streams. The steadiness of horizontal displacement is indicated by a definite correlation between the size of streams and the amount of offset. The smallness of

individual displacements is indicated by the fact that but few streams have been forced to vacate any portion of their channels. Additional evidence of offsetting is found in the asymmetry of the fans of the larger streams.

Presented extemporaneously. Discussed by Messrs. H. O. Wood, G. D. Louderback, and W. M. Davis.

CERTAIN INFERENCES REGARDING THE NATURE OF THE MOVEMENTS ALONG THE HAYWARD FAULT ZONE

BY JOHN P. BUWALDA

(*Abstract*)

San Francisco Bay lies on the depressed San Francisco-Marin block. The eastern margin of this block is made almost entirely of pre-Cretaceous rocks from San Pablo Bay south for at least thirty-five miles. The adjacent portion of the elevated Berkeley Hills block bears several thousand feet of Cretaceous and Tertiary formations. It is inferred from these facts that at an earlier period in the history of movement along the Hayward fault-zone the topographic relations of the two blocks were the reverse of those now existing. The Cretaceous and Tertiary strata were largely swept off the western block while it stood high. While in this relative position, parts at least of both blocks were reduced by erosion to old age. A rather unusual phenomenon then transpired: differential movement of the two blocks occurred, in which the direction of the vertical component was reversed. Hence the present western face of the Berkeley Hills presumably replaces a former eastward-facing scarp. The present face is due in part to warping, in part to the resumption of movement with reversed vertical component on the Hayward fault. The first mile or two of the face south of the University of California campus is a typical fault-scarp. Farther south, for a few miles from Lake Temescal on, warping appears to have been more important, particularly in the depressed block.

A rather recent northward shift of the San Francisco-Marin block of at least 1,400 feet is indicated by the sharp offset of Strawberry Creek at the fault and the projection, from the south, of a ridge of Franciscan bedrock across the mouth of Strawberry Canyon. The deposits mantling this ridge, as revealed in recent cuts, do not resemble the materials being transported by Strawberry Creek, but consist largely of angular fragments of Chico sandstone, among which occur small masses of serpentine. It is probable that the deposit formed in part as a fan at the mouth of Hamilton Gulch, a short drainage course next south of Strawberry Creek, in which an area of serpentine is exposed.

Read from manuscript. Discussed by Messrs. H. O. Wood, G. D. Louderback, and W. M. Davis.

GEOLOGICAL STUDIES IN THE SAN ANTONIO AND NACIMIENTO RIVER VALLEYS, MONTEREY COUNTY, CALIFORNIA

BY R. W. PIKE

(*Abstract*)

The formations exposed along the upper portions of the San Antonio and Nacimiento rivers from younger to older are:

Age.	Formation name.	Character of formation.
Recent.	.....	Gravel of angular diatomite fragments.
Unconformity.		
Pliocene.	Paso Robles.	Gravel of rounded igneous pebbles.
Unconformity.		
Miocene.	Monterey.	Diatomite.
	Vaqueros.	Graywacke and sandstone.
Unconformity.		
Jurassic.	Franciscan.	Sandstone, serpentine, chert and jasper, lentils, schist.
Unconformity.		
Paleozoic.	Santa Lucia.	Granite, pegmatite dikes, gneiss, marble.

The tangential compressive stress which has deformed the region at various intervals from the Paleozoic to the present has been transmitted northeastward from the continental margin. The origin of this stress, as discussed by R. T. Chamberlin in the October-November issue of the *Journal of Geology*, 1924, results from a greater sinking of the oceanic segments in respect to the continental segments.

Axes of folds are sinuous, though the general trend is northwest and southeast. Axial deformation has been the result of both stretch and shear along "planes of no distortion," as expressed in the strain ellipsoid.

The Santa Lucia and Franciscan are so deformed that individual beds can not be traced for sufficient distance to work out the structure or obtain an approximate thickness. The Vaqueros, although lying nearer the origin of deformative stress, has been moderately folded, whereas the Monterey is crumpled and overturned. The Paso Robles gravels have been slightly folded, and recent gravels in the San Antonio River valley gently tilted toward the southwest.

Read by title in absence of the author.

RELATIONSHIPS OF THE MARINE AND THE FRESH-WATER TERTIARY OF WESTERN NORTH AMERICA, BASED ON RECENT COLLECTIONS OF PLANT FOSSILS

BY RALPH W. CHANEY

(*Abstract*)

The flora from the Tejon of western Washington has no known equivalent in the fresh-water deposits of the Great Basin. There are, however, several

species in an associated flora of Oligocene age which are found in the Oligocene of the John Day Basin. The marine phases of both these Washington floras are known also in western Oregon. No Miocene floras have been collected in western Washington or in western Oregon; they are present in west-central California, and contain numerous species which relate them to the Miocene floras of the Great Basin in Nevada and Oregon.

Presented extemporaneously. Discussed by Prof. G. D. Louderback.

CERTAIN STRUCTURAL FEATURES INDICATED ON THE NEW COAST AND GEODETIC SURVEY RELIEF MAP OF THE PHILIPPINE ISLANDS

BY WARREN D. SMITH

Presented extemporaneously and illustrated with lantern slides.

OCCURRENCE OF PHOLADOMYA IN THE MIOCENE OF CALIFORNIA

BY BENJ. F. HAKE

(*Abstract*)

In the course of field-work near Bakersfield, Kern County, California, a well-preserved specimen of Pholadomya was found in beds which also yielded a good Temblor (Miocene) fauna. Pholadomya has not, so far as is known, been hitherto found in beds younger than Eocene age, but the conditions under which the specimen was found make it appear certain that this genus actually lived on, at least in some localities, into Miocene time. A description of the new species is included in the paper.

Presented extemporaneously. Discussed by Messrs. B. L. Clark and C. Stock.

ANTILOCAPRID GENUS MERYCODUS FROM THE BARSTOW MIOCENE AND RICARDO PLIOCENE

BY E. L. FURLONG

Read from manuscript. Discussed by Messrs. C. Stock and J. P. Buwalda.

DOGS OF THE RICARDO PLIOCENE, MOHAVE DESERT, CALIFORNIA

BY CHESTER STOCK AND E. L. FURLONG

Presented extemporaneously from notes. Discussed by Messrs. W. D. Smith and E. L. Furlong.

EFFECT OF THE WIND IN SAN JOAQUIN AND SALINAS VALLEYS

BY R. D. REED

(*Abstract*)

The effect of a dominant wind in carrying dust from exposed slopes and depositing it on lee slopes has been noted by many geologists in all part of

the world. Accumulation of dust on stoss slopes has, however, not often, or perhaps never, previously been described. The existence of this condition in a wide area of the southern Salinas Valley suggests the necessity of some reworking of current theories.

Of the various possible explanations, the favored one is that mild south winds, aided by the greater dryness of the south slopes and by the more abundant vegetation of the north slopes, are able to do more effective transporting of material in this region than the much stronger north winds.

Presented extemporaneously. Discussed by Messrs. W. D. Smith, B. F. Hake, and J. P. Buwalda.

GEOMORPHOLOGY OF THE ISLAND OF MAUI, HAWAII

BY NORMAN E. A. HINDS

(*Abstract*)

The islands of Maui, Molokai, Lanai, and Kahoolawi, which lie between Oahu and Hawaii, are the emergent summits of one of the principal volcanoes of the subarcuate Hawaiian range. Six major eruptive centers are represented on these islands; two each on Maui and Molokai, one on Lanai, and one on Kahoolawi. The eastern member of the Maui doublet is a young lava dome comprising more than five-sixths of the area of the island (728 square miles) and rising to an elevation of 10,032 feet. The original constructional surface and the many parasitic cinder cones are well preserved, except on the heavily watered, lower portions of the windward (northern, eastern, and southeastern) slopes, where numerous streams have cut deep gorges into the flanks of the dome. These gorges are separated by broad, practically undissected, tabular interfluves. The leeward slopes and the upper portion of the windward slopes are broken in only a few places by stream valleys. Low sea-cliffs have been cut into the windward coast; the leeward coast shows practically no cliffing. At the summit of the mountain is a great faulted depression 7.8 miles in length and 2.3 miles in width; the walls are slightly dissected, steeply sloping scarps from 2,000 to 2,500 feet in height. Two fault-gaps, one on the northern and one on the eastern side, breach the walls of the depression. The depression has been explained both as a volcanic rent and as a volcanic sink. Insufficient field-work has been done to determine the exact nature of the dislocation which took place.

The principal eruptive center on east Maui probably became extinct in the late Pleistocene. Activity has continued intermittently at subordinate centers; the last of these minor eruptions took place in 1750. The principal center appears to have been finally sealed. Further eruptions may be expected at subordinate vents.

West Maui (elevation, 5,788 feet) is a much smaller and older dome, which has been greatly dissected by many streams radiating from a small, centrally located summit plateau, the center of heaviest rainfall and the principal watershed on the mountain. The relief is submature, but the heavier precipitation over the windward (northern and northeastern) slopes has caused the development of a greater number of streams and consequently more ex-

tensive dissection of that section of the dome. The small summit plateau is a remnant of the constructional surface, which has been preserved because the headward growth of the streams has not yet reached its ultimate goal. The northern and northeastern coasts have been magnificently cliffed; low cliffs also have been eroded locally into the leeward coast.

Judging from the extent of fluviatile and marine erosion, the principal eruptive center on west Maui probably became extinct during the late Tertiary. Subsidiary activity continued intermittently for a long period of time.

Presented extemporaneously. Illustrated with lantern slides.

CLASSIFICATION OF OCEANIC ISLANDS

BY W. M. DAVIS

(*Abstract*)

Oceanic islands, mostly of volcanic origin, may be classified according as their sculpture is chiefly accomplished by glacial and wave erosion if they are situated in the cold seas of the frigid zones, by stream and wave erosion if situated in the cool seas of the temperate zones and of the eastern torrid oceans, and by stream erosion alone if persistently surrounded by coral reefs in the warmer seas of the torrid zone.

In consequence of climatic changes in the Glacial period, certain islands on the frigid margin of the cool temperate seas were for a time glaciated. Now deglaciated, they show the effects of glacial sculpture better than do the still-glaciated islands of the frigid zones.

Likewise, the reefs of certain islands in the cool marginal belt of the warm or coral seas lost their living reef-builders for a time in the Glacial period; so that, as postulated in Daly's glacial-control theory of coral reefs, the dead reefs were cut away and the lagoon floors were more or less worn down by the waves of the chilled and lowered ocean—that is, by low-level abrasion—and the shores of the islands themselves were more or less cliff; but in post-Glacial time, what with the rising and warming of the ocean nearly to normal measures again, these marginal-belt islands have regained reef protection in less or greater measure. Such islands are therefore more cliff than the islands that have been persistently reef-protected in the warm seas, but are, as a rule, less cliff than the never-protected islands of the cool seas. The marginal-belt islands, as thus defined, are found in a belt about 5 degrees wide on the north and south sides of the Pacific coral seas, and also in the Lesser Antilles of the Atlantic. Although disappointingly few in number, they offer means of recognizing the effects of the Glacial period in the ocean, and of defining the area over which coral reefs were killed and cut away during that period.

Oceanic islands may also be classified as rising, stationary, or sinking. Rising islands will exhibit benches cut by waves or built by coral reefs, according to the latitude of their occurrence. Such islands are relatively few in number.

Stationary islands in the cool seas would in time be reduced to submarine platforms, of small depth if their truncation be accomplished by wave action at normal ocean level, at somewhat greater but still moderate depth if trun-

cated by low-level abrasion in the Glacial period. Unless volcanic islands are all of recent date in the cool seas, a fair number of completely truncated islands should now be found there in the form of shallow banks; but such banks are almost unknown in the cool seas. Hence volcanic islands of ancient eruption must be rarities in those seas, unless, instead of standing stationary at one level, they have suffered long-continued subsidence, in which case their disappearance might be due to deep submergence more than to shallow abrasion.

That stationary volcanic islands have been rare and subsiding islands abundant in the warm seas is well testified not only by the good-sized, drowned-valley embayments which there indent the shorelines of reef-encircled islands to a greater breadth and rock-bottom depth than can be accounted for by low-level erosion in the Glacial period, but also by the occurrence of numerous island-free atolls, undoubtedly based on former volcanic islands, in latitudes where the prevailing absence of such cliffs as characterize the marginal belt islands proclaim the long-continued persistence of protecting coral reefs, and therefore the exclusion of abrasion as a means of destroying the vanished islands. And be it noted that, although an island may sink in the coral seas, it is not then altogether lost, as would be the case in the cool seas, but is memorialized by the atoll that grows up from it—unless, indeed, it sinks too rapidly for the construction of such a memorial. The abundance of atolls in the warm seas makes the extreme rarity of shallow banks, such as would result from the truncation of early formed stationary volcanic islands in the vast extent of the cool seas, all the more striking and significant.

Not only so. As soon as the marginal belt of the coral seas is reached, shallow banks, almost unknown in the cool seas, become relatively abundant. Some of them, now bearing imperfectly developed reefs, are of remarkable extent. It seems unreasonable to regard these banks as the result of abrasion on stationary islands, for that involves the assumption that stationary islands are limited to narrow climatic belts of intermediate temperature, while subsiding islands prevail in the great breadths of the cooler and the warmer seas. Hence these marginal-belt banks are taken, as above intimated, to be the somewhat aggraded platforms cut by the low-level abrasion of preglacial or interglacial coral reefs and their lagoon floors in the Glacial epochs of the Glacial period; and it may now be added that those lost reefs are, like the persistent reefs of the coral seas, best explained as having been built up from slowly sinking islands.

This discussion leads to the conclusion that coral reefs, especially those of the coral seas, are best explained according to Darwin's theory of long-continued upgrowth on slowly or intermittently sinking foundations, such as subsiding volcanic islands may furnish; but that a limited modification of that theory by the action of low-level abrasion, as proposed by Daly for practically all reefs, should be accepted for the narrow marginal belts of the coral seas, yet without accepting also Daly's postulate of prevalently stationary islands.

Presented extemporaneously.

GLACIATION IN THE BITTERROOT MOUNTAINS OF MONTANA

BY JEANNE RUSSELL

(*Abstract*)

The Bitterroot Range in central western Montana, on the Idaho-Montana boundary line, is structurally one long fault-block dipping from 18 to 26 degrees east, the axis of the range being in a north and south direction. The prevailing rock of the district is a light gray quartz monzonite. Along the eastern border of the range the granite has been made schistose by pressure and shearing at the time of the fault, producing a zone of gneiss four miles in width and extending the length of the range.

The Quaternary glaciation of the range is peculiar in some respects. The higher altitudes of the mountains occur in the southern part, where several peaks attain an elevation of 10,000 feet, and there the glaciation has been intense, gradually diminishing farther north as the altitude decreases. The moraines of Lost Horse Creek, well south in the range, are 800 feet high and 3½ miles long, while those of Fred Burr Creek, 17 miles north, are barely 100 feet in height and very illy defined. There seem to be three distinct stages in the weathering of the material in the moraines, the material in the oldest set of moraines being so weathered that it crumbles at a blow. Of the two younger stages, the rocks of one can be chipped and cracked fairly easily, while that of the most recent glacier can not be cracked with the hammer. The boulders of all three stages are composed of the same material—the prevailing quartz monzonite of the district. The conclusion is reached that there were two epochs of glaciation, the last divisible into two periods. Deposits of the three periods are clearly seen in Lost Horse Creek; moraines representing the oldest and the most recent glaciations are found in Blodgett and Mill Creeks, 12 and 15 miles farther north, respectively, while deposits of the two later periods only are apparent at Fred Burr, 17 miles north of Lost Horse Creek.

An exact statement of geologic history is difficult because of the absence of fossiliferous sedimentary formations for correlation. A Triassic bed a little southwest of the range shows the intrusive character of the quartz monzonite. An uplift of great importance probably accompanied this intrusion, followed by long-continued erosion to remove overlying sediments and expose the granite of the batholith. Another uplift, accompanied by faults, occurred later, probably in Cretaceous time. At this time the Bitterroot Mountains were faulted up, the plane dipping uniformly 18 to 26 degrees and the southern part of the range being raised in relation to the northern. Miocene rhyolites and ash deposits are found at several localities in the Bitterroot Valley and the base of the Bitterroot Range. Severe glaciation occurred in Quaternary time and was carried to an advance stage of the Glacial cycle.

Presented extemporaneously.

GEOLOGY OF CORMORANT ISLAND, SALTON SEA, IMPERIAL COUNTY, CALIFORNIA

BY AUSTIN F. ROGERS

(*Abstract*)

A small dome-shaped rock mass, known as Cormorant Island before the recession of Salton Sea, consists largely of tridymite (a high-temperature form of silica) and feldspar (probably barbierite or soda orthoclase). Field observation, microscopic examination, and chemical analyses all prove that the tridymite-feldspar rock was formed from a typical rhyolitic obsidian. Intermediate stages contain cristobalite (another high-temperature silica mineral). The final product, a light gray, banded, porous rock consisting essentially of tridymite and barbierite, constitutes a metamorphic rock. No special name, however, is given to this newly recognized rock type. The metamorphism was brought about by hot gases. A fumarole occurs on the "Island," and hot springs and mud volcanoes are found in the region.

Presented extemporaneously and illustrated with lantern slides.

PRESENT STATUS OF THE PRECAMBRIAN GEOLOGY OF NORTHERN NEW YORK

BY WILLIAM J. MILLER

(*Abstract*)

The purpose of this paper is to discuss the main types of pre-Cambrian rocks of the Adirondack region, with special reference to the problems of their origin, structure, and age relations. Certain differences of opinion in regard to these problems, as expressed by several workers in the field, are particularly considered. The present writer's conclusions, based upon many seasons of field-work, are summarized.

The Grenville series, comprising the oldest known rocks of the region, are highly crystallized strata with moderately well-developed foliation parallel to the stratification. With the probable exception of the northwestern side of the region, there is no evidence that the Grenville series was ever severely folded or compressed. True Grenville strata are much less abundant than was formerly supposed.

The numerous bodies of ophitic gabbro were for some time regarded as younger than the syenite-granite series. They are now known to be largely, if not wholly, older than the syenite granite.

The great bodies of anorthosite may be genetically related to the gabbro, but the evidence is not clear. The anorthosite is not, however, considered to be a variant of the syenite granite of the region, as argued by Bowen, but rather it is considered to be distinctly older than the granite. New evidence in support of this view has very recently been obtained.

The syenite-granite series, with its wide variations in composition, texture, and structure, and with its wealth of satellitic dikes, makes up by far the greatest bulk of all the Adirondack rocks. It is believed that no convincing evidence has been presented to prove that there are two granites of widely

different ages, the conclusions of Cushing and of Alling notwithstanding. The foliation of the syenite-granite series is exceedingly variable in degree and direction, and it is considered to be essentially a primary foliation produced during the consolidation of the magma.

The mixed gneisses are the most troublesome of all to interpret. They seem to be mainly granite-soaked gabbro and Grenville, particularly in the form of various garnetiferous, banded, and porphyritic gneisses. Many rocks formerly classed as Grenville and others of unknown age and origin quite certainly fall in this category.

Diorite-gabbro dikes, and still later diabase dikes, sharply cut all previously mentioned rocks.

Presented extemporaneously and illustrated with slides. Discussed by Messrs. H. W. Turner and W. M. Davis.

ORIGIN OF THE LESSER ANTILLES

BY W. M. DAVIS

(*Abstract*)

Nearly all the islands of the Lesser Antillean chain appear to be members of an evolving sequence, which begins with single or multiple volcanic cones, the earlier ones of which, like the foundation of Antigua, seem to have been built on a subsiding Eocene land-bridge between the Greater Antilles and South America, before its submergence; and the later ones, like the young cones of Saba and Nevis, long after its submergence. Remnants of the land-bridge, consisting of deformed and greatly eroded stratified rocks, largely covered with dissected volcanic masses and not wholly submerged, are still seen in the Virgin Islands. The slow subsidence of the progressively dissected volcanic islands permitted the upgrowth of coral reefs around them, and barrier reefs and atolls, exemplifying Darwin's theory of coral reefs, are believed to have been thus developed in pre-Glacial and inter-Glacial time.

This simple evolutionary sequence of island and reef development has been complicated in two ways.

At any stage of its first-cycle evolution an island and its reef may have been uplifted and exposed to a second cycle of erosion; and, then again subsiding, reefs of a second generation may have grown up around it. Further, whatever stage of growth the coral reefs of either generation had reached around one-cycle or two-cycle islands when the Glacial period arrived, they were then cut away, their lagoon floors were more or less abraded, and the spur ends of the dissected and more or less embayed volcanic islands were moderately cliff by the waves of the lowered and chilled ocean, as postulated in Daly's Glacial-control theory of coral reefs, thus leaving the islands surrounded by reefless platforms; and in post-Glacial time, when the ocean seems not yet to have regained its pre-Glacial or inter-Glacial temperature, the platforms are more or less aggraded as circuminsular banks, on which the present-day reefs are only timid novices; for they rise, discontinuously and imperfectly, well back from the margin of the banks, very unlike the vigorous veterans of the Pacific coral seas, which stand at the outer margin of their

lagoon floors and fall off to deep water. These novices may therefore be called bank reefs. Thus interpreted, the Lesser Antilles appear to lie in the marginal belt of the Atlantic coral seas, between the cool seas of the open Atlantic, where, as in the eastern Pacific, islands have not had reefs around them even in non-Glacial epochs, and the warm seas of the Gulf of Mexico and the Caribbean, where islands did not lose their reefs even during Glacial epochs.

Various members of the Lesser Antilles may be reasonably correlated under the above scheme, as follows:

The Saints, a small group of islets next south of Guadaloupe, are of earlier origin than the young cone of Saba, and seem to represent a single volcanic island, well dissected in a single cycle of erosion, resolved into separate islets and reef-encircled during subsidence, and now moderately clift on their outer slopes as if by low-level abrasion, for they are surrounded by a shallow bank, apparently representing an abraded barrier reef and lagoon floor, on which new reefs are imperfectly established. Redondo, a single residual stack north of Montserrat, surrounded by a shallow bank with imperfect reefs, is further advanced toward extinction by subsidence and abrasion in a single cycle of evolution. Several small, subcircular banks are believed to represent former atolls, truncated by low-level abrasion, and now more or less aggraded, with imperfect bank reefs back from their margin. Marie Galante, in the Guadaloupe group, is a one-cycle atoll of small size, very recently uplifted, but as yet little dissected in its second cycle. Sombrero, southeast of the Virgin Islands, is a well-advanced two-cycle example; it is the remains of a one-cycle atoll, which in consequence of earlier uplift than Marie Galante is now rimmed with plunging cliffs of a second cycle that descend to a shallow bank. Antigua is of much more advanced development; its Eocene volcanic foundation is believed to have subsided so greatly that its barrier reef reached the atoll stage in Oligocene time, when it was uplifted with a slant to the northeast and worn down to moderate relief, thus revealing the volcanic foundation in its southwestern half beneath the beveled atoll limestones which occupy its northeastern half. During its degradation it again subsided, thus giving it for the second time an embayed shoreline and permitting the development of a barrier reef of the second generation. This reef was cut away and the spur ends of the island were moderately clift by the relatively short-lived, low-level abrasion of the Glacial period, and imperfect bank reefs are now growing up on the platform then produced, which is now aggraded to a shallow bank.

Presented extemporaneously.

CYPRESS PLAIN, WESTERN ALBERTA

BY ANDREW C. LAWSON

(*Abstract*)

An application of the doctrine of isostasy to the physiographic development of western Alberta.

Read by the Secretary in the absence of the author. Discussed by Messrs. W. M. Davis and G. D. Louderback.

PRELIMINARY STATEMENT ON THE GEOLOGY OF THE WARNER RANGE, IN NORTHEASTERN CALIFORNIA

BY RICHARD J. RUSSELL

(*Abstract*)

The Warner Range is situated in the northeastern corner of California. It extends north and south for about seventy miles. The width varies from a minimum of about eight to a maximum of about twenty miles. The summits rise above the elevation of Surprise Valley to the east some 2,500 to 3,000 feet in the north and as much as 5,000 feet in the south.

The greater portion of the range is composed of andesitic agglomerate, tuff, and intercalated flows. Concordantly above this series is a sheet of basalt overlain irregularly by rhyolite and obsidian. This basalt is widespread in its distribution in the adjacent portions of California, Nevada, and Oregon. Plant and animal remains indicate a Miocene or Pliocene age for the andesitic series. The basalt is evidently younger than the Columbia lava of central Oregon, as it overlies beds containing vertebrate remains having lower Pliocene affinities.

Orogenically the range is representative of one of the simplest types of Basin Range structure. Its eastern face is a bold escarpment resulting from normal faulting on planes dipping at about sixty degrees. In its southern half the basalts form gentle dip slopes toward the west. A western escarpment, of increasing proportion toward the north, changes the tilted block into a horst. Presumably the period of faulting was initiated in the Pliocene, or at some later date, and has continued up to the present.

The range is dissected by youthful stream canyons. The summits are slightly glaciated above an elevation of about 8,000 feet. Several small corrie lakes are left as a result of this glaciation. Several other lakes have been formed as the result of landslide dams.

Presented extemporaneously. Discussed by Messrs. W. D. Smith W. M. Davis, and G. D. Louderback.

SCARP OF THE TSIN LING SHAN, CHINA

BY GEORGE D. LOUDERBACK

(*Abstract*)

The north-facing scarp of the Tsin Ling Shan extends in an east-west direction for over 200 miles and probably much farther. It is the southern boundary of the chief loess deposits of China. Its form, topographic discordance, faceted spurs, indifference to structure and rock composition, and relation to a basal fault indicate that it is an eroded fault-scarp. No evidence was found suggestive of thrusting, but all observations accord with normal faulting, initiated probably in late Tertiary and continued into the Recent period.

Some of the morphologic features of fault and scarp will be described and their relation to the loess and to later dissection outlined.

Presented extemporaneously and illustrated with lantern slides.

ANNUAL DINNER

The annual dinner, under the auspices of the Le Conte Club, was given at the Faculty Club and was attended by forty-five fellows and guests.

Register of the 1925 Meeting

FELLOWS

Eliot Blackwelder
John D. Boutwell
John P. Buwalda
Bruce L. Clark
William M. Davis
Arthur S. Eakle
James Hill
George D. Louderback
William J. Miller
A. F. Rogers
Warren D. Smith
W. S. Tangier Smith
Henry W. Turner
Harry O. Wood

GUESTS

Charles Anderson
E. R. Baddley
T. L. Bailey
W. F. Barbat
R. J. Buckley
F. Buss
C. Cassell
C. Church
A. H. Dean
Herbert Elftman
A. H. Elftman
C. K. Eliashevich
Walter English
F. H. Frost
E. L. Furlong
V. I. Gavrilovich
C. B. Gentle
B. F. Hake
N. E. A. Hinds
R. S. Holway
H. W. Hoots
C. D. Hulin
L. W. Hunt
G. K. Kribbs
J. B. Macelwane
Marsdon Manson
E. M. Mitchell
E. A. Obering
E. N. Pennebaker
R. W. Pike
W. B. Rand
William Rankin
R. D. Reed.
Jeanne Russell
R. J. Russell
C. O. Sauer
H. G. Schenck
J. P. Smith
Dwight Smith
Gertrude J. Stevenson
Chester Stock
C. Swanson
Nellie M. Tegland
E. G. Tickell
A. G. Vestal
L. N. Waterfall
G. S. Wilcox
Marion Wilcox

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 37, PP. 225-254 MARCH 30, 1926
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE SEVENTEENTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT NEW HAVEN, CONNECTICUT, DECEMBER 28-30, 1925.

R. S. BASSLER, *Secretary*

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Session of Monday, December 28

No special meeting of the Society was scheduled for this day, and the members met in general session, with the Geological Society of America, in Sterling Laboratory, to hear the geological papers of general interest. In the evening our members listened to the address on "Geological climates" by Prof. Wm. B. Scott, the retiring President of the Geological Society of America. Following this address they participated in the complimentary smoker given by Yale University, in Byers Memorial Hall, to the Geological Society of America and its affiliated societies.

Session of Tuesday, December 29

At 9 a. m. the Society met in joint session with the Geological Society of America for the reading of papers on stratigraphic geology.

Stratigraphic papers presented in joint session with Geological Society of America

Pre-Cambrian and Paleozoic geology of Fortune Bay, Newfoundland

BY NELSON D. DALE

This paper was read by title.

Relations of the Guadalupian group

BY N. H. DARTON AND J. B. REESIDE, JR.

CORRELATION OF THE METAMORPHIC ROCKS OF NORTHEASTERN CONNECTICUT WITH THOSE OF ADJACENT PORTIONS OF MASSACHUSETTS

BY WILBUR G. FOYE

PROBLEM OF THE PLIOCENE IN THE PACIFIC COAST AND GREAT BASIN REGIONS

BY JOHN C. MERRIAM

STUDIES IN GEOLOGY AND PALEONTOLOGY OF THE TERMINAL PLEISTOCENE AND EARLY RECENT AND ITS BEARING ON THE STUDY OF EARLY MAN IN AMERICA

BY JOHN C. MERRIAM

ORIGIN OF A KEWEENAWAN BOULDER CONGLOMERATE

BY E. S. MOORE

SUMMARY OF DISCOVERIES IN VERTEBRATE PALEONTOLOGY IN THREE SEASONS OF FIELD EXPLORATION IN MONGOLIA—1922, 1923, AND 1925

BY HENRY FAIRFIELD OSBORN AND WILLIAM D. MATTHEW

JURASSIC FORMATIONS OF EASTERN UTAH

BY JAMES GILLULY AND JOHN B. REESIDE, JR.

BURIED PENNSYLVANIAN CHANNELS AND SAND BARS OF EASTERN KANSAS

BY JOHN L. RICH

SILURIAN ROCKS OF ILLINOIS

BY T. E. SAVAGE

UPPER CRETACEOUS SHORELINE IN UTAH

BY EDMUND M. SPIEKER AND JOHN B. REESIDE, JR.

FOSSIL RHIZOPODS OF THE GREEN RIVER OIL SHALE

BY W. H. BRADLEY [1]

PRE-CAMBRIAN SEDIMENTATION IN NORTHERN COLORADO

BY MARGARET BRADLEY FULLER [2]

GROUND-WATER PROBLEMS ON THE BARRIER BEACHES OF NEW JERSEY

BY DAVID G. THOMPSON [3]

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[1] Introduced by J. D. Sears.
[2] Introduced by R. T. Chamberlin.
[3] Introduced by Kirk Bryan.

Dedication of Peabody Museum of Natural History

The Society adjourned at 1 p. m. for luncheon, meeting again at 2.30 for the exercises in connection with the dedication of the Peabody Museum of Natural History. President Angell presided over the dedication ceremony, and the main speakers of the occasion were two former presidents of our Society—Prof. Charles Schuchert and Prof. Henry Fairfield Osborn. Professor Schuchert traced "The rise of natural history museums in the United States," and Professor Osborn spoke on "The origin of species III." These exercises were followed by a reception to the guests and inspection of the Museum, which occupied the rest of the afternoon.

ANNUAL DINNER

Tuesday, at 7 p. m., the Society met with the Geological Society of America and other affiliated societies in the annual dinner, which was held at Memorial Hall of Yale University.

Session of Wednesday, December 30

President Lull called the seventeenth annual meeting of the Society to order in general session at 9.20 a. m. in Sterling Laboratory. The first order of business was the report of the Council.

REPORT OF THE COUNCIL

To the Paleontological Society, in seventeenth annual meeting assembled:

The business of the Society has been conducted as usual, partly by correspondence and also by two Council meetings, one immediately after the sixteenth annual meeting, at Ithaca, New York, and the second just preceding the present session. The Council's administration of the Society's business is briefly summarized in the following reports:

Secretary's Report

To the Council of the Paleontological Society:

The Secretary's report for the year ending December 28, 1925, is as follows:

Meetings.—The Proceedings of the sixteenth annual meeting, held at Ithaca, New York, December 29 to 31, 1924, have been published in volume 36, number 1, of the Bulletin of the Geological Society of America, pages 211-240.

The Council's proposed nomination for officers for 1926 was mailed to the members on March 1, 1925. At the same time it was announced that the next meeting of the Society would be held at New Haven, Connecticut, December 28-30, 1925, as the guest of Yale University, on the occasion of the dedication of the Peabody Museum of Natural History.

Membership.—Our loss by death during the year has been heavy, for Dr. John M. Clarke and Prof. Gilbert Van Ingen, two of our charter members, and Mr. Edwin J. Armstrong and Dr. Herrick E. Wilson have passed away. One member has resigned. Nine new members have just been elected and six nominations await action at the present meeting. Two of our members have been elected to fellowship in the Geological Society of America this year. The result of these various changes leaves a total number of members of 271 at the end of 1925.

Publications.—The publications of the Society for the year consist of the proceedings, the presidential address, and several articles, all appearing in the Bulletin of the Geological Society of America.

Respectfully submitted,

R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 26, 1925.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 29, 1925:

RECEIPTS

Cash on hand December 26, 1924		$997.31
Membership fees for 1925		312.00
Interest, Connecticut Savings Bank		38.76
Fee for foreign postage		1.00
		$1,349.07

EXPENDITURES

Secretary's office:		
Secretary's allowance (1)	$100.00	
Clerical aid (2)	25.00	
Office expense (3)	60.25	
		$185.25
Treasurer's office:		
Treasurer's allowance (4)	$25.00	
Stationery (5)	3.35	
		28.35

Pacific Coast Section:			
Annual assessments of the American Association for the Advancement of Science for 1922-1925 (9)	$20.00		
		20.00	
Geological Society of America:			
150 reprints from Bulletin of the Geological Society of America, volume 35 (6)	$121.35		
125 reprints from Bulletin of the Geological Society of America, volume 36, pages 211-240 (7)	12.48		
175 reprints from Bulletin of the Geological Society of America, volume 36, pages 263-278 (8)	13.42		
		147.25	
			380.85
Balance on hand December 29, 1925			$968.22
Net decrease in funds			29.19
Outstanding dues (3 for 1924, 17 for 1925)			60.00

Respectfully submitted,
(Signed) CARL O. DUNBAR,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 29, 1925.

APPOINTMENT OF AUDITING COMMITTEE

Following the conclusion of the Council's report, President Lull appointed Dr. A. F. Foerste and Prof. J. J. Galloway as a committee to audit the Treasurer's accounts.

ELECTION OF OFFICERS AND MEMBERS

The Secretary then announced the results of the ballots for the election of officers for 1926 and of new members, as follows:

OFFICERS FOR 1926

President:

STUART WELLER, Chicago, Ill.

First Vice-President:

E. H. BARBOUR, Lincoln, Nebr.

Second Vice-President:

BRUCE L. CLARK, Berkeley, Calif.

Third Vice-President:

MIGNON TALBOT, South Hadley, Mass.

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

CARL O. DUNBAR, New Haven, Conn.

Editor:

WALTER GRANGER, New York City

NEW MEMBERS FOR 1926

OSCAR M. BALL, Agricultural and Mechanical College of Texas, College Station, Texas.

CAREY G. CRONEIS, 1 Craigie Street, Cambridge, Massachusetts.

JULIAN W. FEISS, 4 East Brown, Princeton, New Jersey.

RICHARD M. FULLÉ, 550 Park Street, Montclair, New Jersey.

GLENN L. JEPSEN, 314 Henry Hall, Princeton, New Jersey.

WILLIAM A. KELLY, Department of Geology, Princeton University, Princeton, New Jersey.

RALPH G. LUSK, 7 Linnæan Street, Cambridge, Massachusetts.

WILLIS P. POPENOE, United States Geological Survey, Washington, D. C.

TOWNER B. ROOT, Box 218, Hamilton, New York.

NEW NOMINATIONS AND ELECTION TO MEMBERSHIP

Six nominations for membership were received too late for the printed ballot. These were then presented to the Society with the approval of the Council:

WALTER W. HOLMES, Waterbury, Connecticut. Retired manufacturer; interested in the collection and study of Florida Pleistocene vertebrates. Proposed by W. D. Matthew and F. B. Loomis.

G. MARSHALL KAY, M. S., Iowa (1925). Assistant Curator of Paleontology, Columbia University, New York City. Proposed by J. J. Galloway and H. N. Coryell.

GAYLE SCOTT, D. Sc., Grenoble (1925). Associate Professor of Biology and Geology, Texas Christian University, Fort Worth, Texas. Proposed by J. B. Reeside, Jr., W. M. Winton, and R. S. Bassler.

FRANK W. ROHWER, 624 Pine Street, Boulder, Colorado. Geologist, Standard Oil Company of California. Interested in fossil Foraminifera. Proposed by E. O. Ulrich and R. S. Bassler.

GRACE ANNE STEWART, Ph. D., Chicago (1922). Instructor in Geology, Ohio State University, Columbus, Ohio. Proposed by J. Earnest Carman and R. S. Bassler.

RALPH B. STEWART, B. S., California (1922). Research assistant in invertebrate paleontology, University of California, Berkeley, California. Proposed by Bruce L. Clark and Chester Stock.

Upon motion, it was voted that the By-Laws be suspended, and that the vote of the Society for the election to membership of these six nominees be cast by the Secretary.

ELECTION OF CORRESPONDENTS

The nominations of six European students who have done outstanding work in paleontology and stratigraphy were then submitted to the Society, with the approval of the Council, for consideration as to election as Correspondents. These nominations are as follows:

Prof. O. T. JONES, The University, Manchester, England. For his work on the Ordovician rocks in the complicated Welsh regions.

Prof. JOHAN KLÆR, University of Christiania, Oslo, Norway. For his excellent work on the Cambrian and Silurian of Norway.

Dr. J. PERNER, Vinohrady, Kollarova ul. 9, Prague, Czechoslovakia. For his work on the Lower Paleozoic beds of Bohemia.

Dr. RUDOLF RICHTER, Viktoria Alle 7, Frankfurt-am-Main, Germany. For his extensive studies, many together with Mrs. Richter, on trilobites, sedimentation and Devonian formations.

Dr. GUSTAV TROEDSSON, Geological Survey, Stockholm 50, Sweden. For his extensive work of high quality on the Ordovician rocks of Sweden.

Dr. A. H. WESTERGAARD, Geological Survey, Stockholm 50, Sweden. For his most excellent, detailed stratigraphic work, particularly on the Olenus series.

The election of these six scientists as Correspondents followed by unanimous vote.

NECROLOGY

Personal recollections and remarks in memory of the four members who died during the past year were then presented by B. F. Howell and the Secretary.

R. S. Bassler referred to the great loss to science of our charter member and former President, Dr. John M. Clarke.

B. F. Howell outlined the life-work of his former teacher and associate at Princeton, Prof. Gilbert Van Ingen.

R. S. Bassler then followed with a résumé of the life of Edwin Armstrong, distinguished engineer of Erie, Pennsylvania, whose researches in Devonian paleontology and stratigraphy were generously placed at the service of the New York State Museum and the United States National Museum.

In the absence of Mr. Frank Springer, with whom Herrick E. Wilson was associated in the study of fossil crinoids, R. S. Bassler gave an appreciation of Dr. Wilson's scientific work.

NEW BUSINESS

Various items of new business were then offered for the consideration of the Society.

Upon invitation from the American Association for the Advancement of Science, the Council of the Paleontological Society took up the consideration of affiliation of the two societies, and favorable action toward this end was recommended. By vote of the members this recommendation was approved.

The nomination by the Council of Dr. W. D. Matthew as representative of the Paleontological Society on the Advisory Board of the American Year Book Corporation was next approved by vote.

The election of the Society's representative on the National Research Council in the Division of Geology and Geography for the three-year term starting July 1, 1926, was next in order. Dr. L. W. Stephenson was chosen for this position.

The invitation of the Japanese Research Council for the Paleontological Society to participate in the Third Pan-Pacific Science Congress, to be held at Tokyo next fall, was accepted, and Dr. T. Wayland Vaughan was nominated as the Society's representative on that occasion.

It was then announced that Biological Abstracts had selected B. F. Howell, of our Society, as editor of the section of paleozoology. Professor Howell's interest in this project and in bibliographic work will insure excellent results from this undertaking for the paleontologists.

The following motion was then presented for consideration:

"*Moved*, That the President be authorized to appoint a committee of three to investigate the feasibility of the Society's recommending and encouraging the adoption and use, so far as practicable, of standard symbols for marking and designating type specimens of fossils, said committee to report to the Society at the next annual meeting its findings concerning the prevailing methods of marking, and, if it considers that the Society should take further action in the matter, to make suggestions as to the nature of such action."

Following brief discussion of this motion, favorable action was voted by the members. President Lull later appointed B. F. Howell (chairman), Charles E. Resser, and P. E. Raymond as a committee for this investigation.

There being no further business, the Society proceeded to the reading of scientific papers in general session, with President Lull in the chair.

PRESENTATION OF PAPERS

The author of the first paper on the program discussed some interesting new methods of casting fossils and illustrated his remarks by type-metal casts. Discussion by Messrs. Ruedemann, Dunbar, and Matthew.

CASTING INVERTEBRATE FOSSILS IN SEALING WAX AND TYPE METAL

BY J. W. FEISS

(*Abstract*)

Experiments in the use of sealing wax and type metal as a substance for the making of casts of small invertebrate fossils have resulted in the development of simple and easy methods which give excellent results. By pouring hot sealing wax over the original specimens coated with glycerine, a perfect imprint results. For making sealing wax and metallic reproductions, molds are made in dental plaster, and after the molds are heated the molten type metal or wax is poured in, forming the cast. Sealing wax has also been found useful for making bases for mounting small specimens, such as brachiopods, in natural attitudes.

In the next paper the author discussed particularly the principles underlying his classification and illustrated the classification itself by lantern slides, in which the evolution of the foraminiferal genera was shown.

REVISION OF THE CLASSIFICATION AND NOMENCLATURE OF FORAMINIFERA

BY J. J. GALLOWAY

(*Abstract*)

The recent revival of the study of Foraminifera, on account of their value in solving stratigraphical and structural problems, has brought out the necessity for more exact definitions of families, genera and species, their rearrangement into a natural system of classification, and the application of the International Rules of Zoological Nomenclature. In the present work about 300 genera of Foraminifera are recognized, each based on the original description and figures of the genotype and distinguished by its morphology and its phylogenetic stage as interpreted from the ontogeny of the species. The genera are arranged into 20 families and 31 subfamilies, each based on genera which seem to be related, as shown by their similar morphology and ontogeny. Geneological trees are constructed to show the relation of the families and the genera to each other. For each genus the author, date, place of publication, the genotype, and the horizon and locality of the genotype are given. This is followed by a complete description and the habitat and geologic range of each genus. The rules of nomenclature are applied consistently for the first time.

The present treatment of families and genera differs from those of Schultze, Reuss, and Brady in the application of the rules of nomenclature, the application of the natural laws of evolution and biogenesis, in the greater precision

in definitions, and the recognition that Foraminifera are as characteristic of different geologic horizons as are many other fossils.

The following paper was presented for the author by B. F. Howell, who then gave his own discussion of this interesting occurrence. In the remarks which followed Professor Howell's paper, it was agreed that until an actual plate, with its substance intact, had been found, the question must remain an open one.

EVIDENCE OF THE PRESENCE OF CHORDATES IN THE CAMBRIAN

BY W. L. BRYANT

(*Abstract*)

Prior to the discovery of Ostracoderms in the Ordovician, it was thought that fishes arose in early Silurian times from ancestors to such generalized types as *Lasanius* and *Thelodus*, and that their predecessors of lower grade were soft-bodied and unlikely to be preserved as fossils. The structure of the Ordovician plates, however, show such specialization as to render it probable that they had already undergone a long evolution of the exoskeleton, and that we may expect to find remains of fishlike animals in much older rocks. Possible evidence of a Cambrian Ostracoderm is found in the impression of a sculptured plate from Vermont found by Professors Schuchert and Howell, which is described under the name of *Eoichthys howelli*.

PROBLEMATICAL FOSSIL, POSSIBLY A FISH PLATE, FROM THE CAMBRIAN PARADOXIDES BEDS OF NORTHWESTERN VERMONT

BY B. F. HOWELL

(*Abstract*)

A small fossil, which appears to be possibly a fish plate, was found during the past summer by Prof. Charles Schuchert and the writer in the Saint Albans shale, a Cambrian formation containing Paradoxides and other marine fossils of a Paradoxides fauna just south of the town of Saint Albans, Franklin County, northwestern Vermont. The fossil will be of great interest if it can be proved to be a fish plate, as it will be the first evidence of the existence of fish or fishlike creatures in the Cambrian and will be thus the oldest vertebrate or chordate fossil yet discovered. The fact that it was found in a shale which contains trilobites and brachiopods, and which was therefore presumably deposited in marine waters, is also interesting as throwing light on the habitat of the early chordates.

The discussion by Professor Patten of newly discovered cephalaspid material in Spitsbergen included lantern slides of remarkably well preserved fossils. Discussion by Doctors Lull and Ruedemann.

NEW OSTRACODERMS FROM SPITSBERGEN

BY WILLIAM PATTEN

(*Abstract*)

Remarkably well preserved Ostracoderms have recently been found by Scandinavian explorers in Spitsbergen. Last summer, aided by a grant of $250 from the Scandinavian American Foundation, I undertook a reconnaissance trip to Spitsbergen in order to determine the feasibility of further exploration in that remote and somewhat difficult region by American students of fossil fishes.

A small hunting boat was chartered in Advent Bay, in which, under favorable ice conditions, I went to northwestern Spitsbergen, going that way, in all, about 400 miles. Some Ostracoderms were obtained, various deposits were located, and the probability of obtaining more valuable material was assured, provided requisite assistance could be obtained.

Many remarkable specimens collected by Major Isachsen are now in the State Museum, Stockholm, under investigation by Professor Stensiö. On my return from Spitsbergen, Professor Stensiö, with rare generosity, placed his beautiful preparations at my disposal. This scientific idealism, so common in theory, so rare in practice, is all the more noteworthy, since the fossils are veritable miracles of anatomical preservation, and of an extinct class of little-known animals where every detail is of the utmost importance. In Professor Stensiö's preparations, blood vessels, cranial nerves, the internal ear, and oral gut lobes are shown with a distinctness and fullness of detail more suggestive of modern anatomical preparations than Paleozoic fossils.

The new facts so unexpectedly revealed are of the greatest significance to all students of comparative anatomy and paleontology. These facts, together with many others I have previously described, clearly and decisively show that the basic structural and functional plan of the Arachnids, such as Limulus, Scorpions, and Eurypterids, is practically identical with that of primitive vertebrates, and fully confirms our belief that the vertebrates are genetically derived from a pre-Cambrian Arachnoid stock.

NEW RECONSTRUCTION OF LASANIUS

BY GEORGE G. SIMPSON

(*Abstract*)

The tremendous advance in our knowledge of anaspidans due to Kiær, together with a study of originals in the Yale Peabody Museum, has made possible a new restoration of *Lasanius*, the most primitive known fossil vertebrate. This reconstruction differs from previous ones chiefly in reversing the dorsal and ventral sides, in showing a mouth and anal fin, in the interpretation of the branchial region, and in the details of the various plates and spines. *Lasanius* very strongly supports the view that the first chordates (beyond which the anaspidans are little advanced) were naked, and that the notochord was, indeed, as ancient as the other diagnostic characters of the group.

The same author followed with an illustrated paper on the evolution of early mammalian teeth. Remarks by Dr. Matthew.

PRE-CRETACEOUS EVOLUTION OF MAMMALIAN LOWER MOLARS

BY GEORGE G. SIMPSON

(*Abstract*)

At the close of the Jurassic there were four distinct types of mammalian lower molars, each one of which seems to have been derived from an essentially monocuspid condition independently of the others. There now appears to be no evidence that the triconodont, symmetrodont, and so-called "trituberculate" molars belong in one series in any sense. They are seen to be independent derivatives on the basis of cusp position, there being strong evidence against any significant cusp migration; and also on the basis of cusp origin—that is, as to derivation of cusps from the original apex, or from its slopes, or from the cingular region. Only one group, that of the pantotheres ("trituberculates"), is of significance as regards the origin of the dominant post-Jurassic types, but it throws much light on this difficult problem.

Newly discovered late Paleozoic vertebrate material in West Virginia was described and illustrated by the specimens by the next speaker. A discussion of Permian vertebrates in general followed, with Messrs. Gilmore, Matthew, Carman, Tilton, and Foerste participating.

PERMIAN VERTEBRATES FROM WEST VIRGINIA

BY JOHN L. TILTON

(*Abstract*)

The following are illustrated and described: portions of a small amphibian skeleton from the Nineveh limestone, a caudal vertebra, stegocephalian footprints in Waynesburg sandstone, coprolites from Middle Lockport limestone, fish scales, and teeth from the Fish Creek shale.

In the next paper, also dealing with vertebrate paleontology, the author presented the phylogeny and classification of this group, illustrating his remarks with lantern slides. Discussion by Doctors Matthew and Troxell.

SOME EARLY TERTIARY RHINOCEROSES AND HYRACODONTS

BY HORACE ELMER WOOD, 2ND

(*Abstract*)

An attempt has been made to restudy and synthesize the available early Tertiary rhinoceros material, in several museum collections.

Restudy of the Eocene hyracodonts gives much additional knowledge of the known forms, together with a new species.

A new species from the Bridger and Uinta Eocene appears to be a primitive true rhinoceros, the first definitely known from the Eocene.

Three new species of *Trigonias* are described, two of which tend toward *"Caenopus" platycephalus*.

The American Oligocene forms at present lumped in *Caenopus* include three distinct lines. A new species is described.

The nomenclature, hypothetical phylogeny, and classification are revised. A revision of the subdivisions of the Perissodactyls is proposed.

In the final paper of the morning session the author gave a résumé of the principles involved in drawing systematic boundaries, and then presented the evidence for the one under discussion. In the remarks which followed, R. S. Bassler outlined briefly the various opinions held as to this boundary.

RELATIVE VALUES OF CRITERIA USED IN DRAWING THE ORDOVICIAN SILURIAN BOUNDARY

BY E. O. ULRICH

This paper will appear in full in the forthcoming part 2 of the Bulletin.

The meeting then adjourned for luncheon.

At 2 p. m. the Society convened and had as its guests visiting archeologists and ethnologists to hear the geological evidence for fossil man in Florida.

A spirited discussion followed Dr. Gidley's presentation, which was illustrated by some of the human remains discovered and by lantern slides. Among the speakers was Dr. Ales Hrdlicka, who made an appeal for closer affiliation between the ethnologists and geologists in studies of ancient man.

FOSSIL MAN IN FLORIDA

BY J. W. GIDLEY

(*Abstract*)

The published reviews and opinions expressed by various authorities regarding the discoveries a few years ago near Vero, Florida, reported by Dr. E. H. Sellards, were reviewed.

These show a wide difference of opinion between the anthropologists and paleontologists regarding the contemporaneity of early man with a Pleistocene fauna in Florida, the former believing that the association of material as reported by Sellards is an unnatural one. Discoveries near Melbourne, about 40 miles north of Vero, made by the Amherst-Smithsonian Expedition of last summer, seem to refute this and to confirm in general Sellards' views regarding the general geology of the region and of the association of remains

of man with those of a Pleistocene fauna, which he considered a natural one. Three important localities were examined in the Melbourne district, all showing similar conditions of deposition and geologic position. The Vero district was also revisited. The general conclusions reached, as a result of the Amherst-Smithsonian Expedition, are that the human remains located belong to the geologic levels in which they were found, and are not the result of later inclusions from the surface through human burials or otherwise; that the human bones and artifacts represent a people contemporaneous with the mammoths and mastodons with whose remains they were found associated, and that the general geologic conditions as interpreted suggest a relatively recent date, either late Pleistocene or even post-Pleistocene, for the extinction of the last survivor of the Pleistocene fauna in the south.

An interesting account, well illustrated by lantern slides, of the Field Museum's paleontologic expedition to South America and of the results attained in the Santa Cruzean and Deseado series of Santa Cruz and the Pliocene-Pleistocene formations of southern Bolivia was then given.

RESULTS OF FIELD MUSEUM PALEONTOLOGICAL EXPEDITION TO ARGENTINA AND BOLIVIA

BY ELMER S. RIGGS

An interesting and unusual occurrence of fossil footprints was next described and illustrated by the author.

FOSSIL FOOTPRINTS FROM THE GRAND CANYON

BY CHARLES W. GILMORE

(Abstract)

Under the auspices of the National Park Service, a locality for fossil footprints in the Grand Canyon National Park, Arizona, discovered by Prof. Charles Schuchert in 1915 was visited by the writer in the fall of 1925 for the purpose of making a collection of these tracks for the United States National Museum and also to prepare an exhibit of them *in situ* on the famous Hermit Trail. Both of these undertakings were successfully carried out.

The collection made for the Museum consisted of a series of slabs some 1,700 pounds in weight and carrying a great variety of excellently preserved imprints. It was found that the tracks occurred in great abundance and variety in the lower half of the formation at this locality and extended laterally for several hundred feet. The tracks occur on the upper surfaces of the inclined laminæ of the strongly cross-bedded sandstone, and, curiously enough, all were found to be pointing in the same direction—that is, up the steep slope of the sandstone layer. Of all the trails collected and the still greater number observed in the field, but one exception was noted to this uphill direction of movement.

The Ichnite fauna of the Coconino sandstone, as known and described in a paper now in press, consists of no less than eight genera and ten species.

Both vertebrate and invertebrate animals are represented by these tracks, and of the former the classes reptilia and amphibia are quite certainly recognized.

The fauna, taken as a whole, shows that its affinities lie nearest to those described from the Carboniferous Coal Measures, rather than to the later Mesozoic Ichnites. This is indicated by the presence in the Coconino of two, and possibly three, genera common to the Carboniferous, whereas not a single genus of the Triassic was recognized. Furthermore, the facies of the fauna is Carboniferous in aspect, as shown by the relatively small size of the animals, all of which are quadrupedal, as contrasted with the considerable number of very large forms and the many three-toed bipedal animals of the Triassic. The Coconino footprint fauna also seems to have closer relationship to the Ichnite fauna from the Middle Coal Measures of Kansas, described by Marsh, than to the more extensive fauna from the Coal Measures of Nova Scotia, described by Dawson and Matthew.

In the absence of the author, Dr. Wieland then read an instructive paper, giving the results of studies of American coal balls.

COAL-BALL STUDIES

BY A. C. NOÉ

(*Abstract*)

A coal ball is a calcareous or siliceous concretion occasionally found in coal seams which were deposited under marine conditions. These concretions frequently contain well-preserved plant fragments. Micro-preparations can be made of coal balls by the use of a diamond saw, and a microscopic examination of these sections reveals the anatomic structure of the plants which formed the coal seam. Almost our entire knowledge of the structure of Carboniferous plants is based on coal-ball investigations. The material for these was formerly supplied exclusively from England and continental Europe, but during the last years a large number of American coal balls became available and were examined in the laboratory of the writer at the University of Chicago. More than twenty-five species have been determined, belonging to the orders of Equisetales, Lycopodiales, Sphenophyllales, Filicales, Cycadofilicales, and Cordaitales: also, organs having angiospermic characters were found. Their determination has provoked a controversy of which the clear gain seemed to be at present the admission that the questionable specimens represent a line of development from Cycadofilicales to Angiosperms. From the study of these American coal balls a large contribution to our knowledge of Paleozoic plant structure is to be expected and fossil plant morphology will no longer be based on almost purely European material.

Dr. Wieland then presented a second paleobotanic paper, illustrated by many lantern slides.

CERTAIN RHÆTIC SEEDS FROM THE MINAS DE PETROLEO, ARGENTINA

BY G. R. WIELAND

(*Abstract*)

These seeds are at present supposed to be those of dicotyledonous plants, and were probably borne in strobili or conelike fruits somewhat like those of the magnolia. If the view is correct, they are quite the oldest of recognized dicotyls, inasmuch as the several Argentine beds referred to the Rhætic appear to be of that age. Closely associated fossils include several finely conserved insects referable to the Homoptera (not the crane fly, as I earlier thought) and the dragon flies. These are the first of South American fossil insects. There are also fine Tæniopteris leaves of supposedly Williamsonian type. A series of these fossils will be shown.

The time for adjournment having arrived, there was no opportunity for the presentation of the papers listed below.

STRUCTURAL CONTOURING IN AREAS OF UNCONFORMABLE FORMATIONS WITH VARIABLE THICKNESSES

BY R. S. BASSLER

(*Abstract*)

The Highland Rim of Tennessee is underlaid by Mississippian formations, some of which have a widespread distribution with uniform thickness, while others are limited to ancient bays of deposition, where the thicknesses vary from 0–250 feet. The problem of structural contouring in such an area is, therefore, complicated by these variations, but it is increased in difficulty by the fact that slight angular unconformities exist between certain of the formations. The effect of these phenomena upon the structural contour maps will be discussed and illustrated.

CAMBRIAN PARADOXIDES BEDS IN NORTHWESTERN VERMONT

BY B. F. HOWELL

(*Abstract*)

Paradoxidian fossils were reported from Franklin County, Vermont, by Edson, Perkins, and Walcott some fifteen years ago, but not much was then known about the beds from which they came. During the past four years the fieldwork of Raymond, Prindle, Dunbar, Sayles, and especially Keith, Schuchert, and the writer, has added much to our knowledge of the stratigraphy and areal extent of these Paradoxides beds and the character and relationships of the fossils. The beds are dark shales, named the Saint Albans formation, which, although they outcrop at only a few places and are known to be fossiliferous in only four of their outcrops, are believed to underlie the mantle of glacial deposits in a continuous or nearly continuous band, which varies from a few yards to a quarter of a mile in width and extends from the vicinity of west Georgia northeast for about 16 miles, to near Highgate. The fossils

appear to belong to a fauna similar to, but not identical with, the *Paradoxides eteminicus* fauna of the lower Paradoxides beds of New Brunswick and possibly to one or more younger Paradoxides faunas.

REVISION OF THE SILURIAN OF SOUTHEASTERN MISSOURI

BY RICHARD FOSTER FLINT AND JOHN R. BALL[1]

(Abstract)

A group of Silurian beds lying in southeastern Missouri have been known heretofore as the Bainbridge limestone and have been considered Niagaran in age. Detailed stratigraphic and paleontologic studies show that these beds are made up of three distinct zones, separated by marked unconformities and correlating with the Edgewood limestone, the Brassfield limestone, and the Niagaran limestone, respectively. It is proposed to restrict the name "Bainbridge" to the beds of the Niagaran division, while the names Edgewood and Brassfield are carried over and applied respectively to the two lower divisions.

FAUNA AND STRATIGRAPHY OF THE SAINT CLAIR LIMESTONE OF ARKANSAS AND OKLAHOMA

BY E. O. ULRICH AND R. D. MESLER

(Abstract)

The Saint Clair limestone, a Silurian formation, was named from exposures in the vicinity of Batesville, Arkansas, and its fauna, so far as then known, was listed and briefly commented on by H. S. Williams in 1900. The collections then in hand were largely made by Gilbert Van Ingen and Stuart Weller. Shortly after—that is, in 1901—Van Ingen published two brief installments of a work in which he proposed to describe the fossils of the formation. The first gives a good account of the "geological relations of the rocks containing the fauna." The second, which, unfortunately, proved to be also the last, gives detailed descriptions, in part without figures, of 12 of the 28 species of trilobites listed by him. In 1902 E. O. Ulrich, during the course of investigations of the Paleozoic formations in north Arkansas, made small collections from the typical and other localities in the Batesville Quadrangle and recognized the formation not only at places farther west in Arkansas, but, in the same year, also at two localities in eastern and central Oklahoma. Since then, as opportunities were presented, he and R. D. Mesler made further collections at the previously known outcrops and exploited others reported by U. S. Geological Survey geologists engaged in mapping concerned areas in the mentioned States. These collections are now worked up, and various groups of the species have been described and illustrated in manuscript. Indeed, the manuscript and figures of the trilobites were practically ready for publication seven years ago. Since and before 1910 the purpose of the authors to work this fauna has had the hearty approval of the late Professor Van Ingen.

The Saint Clair fauna, though consisting mainly of small species, is one of the most interesting in America. Considering the relatively small thickness of

[1] Introduced by Carl O. Dunbar.

the formation, it is also one of the largest in number and variety of species. Williams's list comprises 69 species. This number has now grown to nearly 200 species, more than half of them new. But a more interesting feature of the fauna is that as a whole it is much more closely allied to the Silurian fauna of Bohemia than to the usual American, British, and Gotlandian faunas of the same period. In fact, many of the Saint Clair species, especially among the brachiopods and mollusks, are practically indistinguishable from Bohemian species described in Barrande's works; and the majority of all the classes have their nearest allies in Bohemia. The distinctness of the Saint Clair fauna from other American faunas of Silurian age is strikingly apparent when we find that only a few of its 200 species are to be found in the relatively near-by Silurian deposits of western Tennessee. Moreover, such of the species as are common to these two areas are long-ranging, more or less decidedly cosmopolitan forms that have, therefore, only low values in precise correlation of formations and the determination of the origin and migrations of marine faunas by littoral or shallow-water paths. How this Bohemian fauna got into north Arkansas is one of the difficult problems offered by these studies of the Saint Clair occurrence.

So far as determined, the Saint Clair limestone fauna consists of 4 crinoids, 9 corals and bryozoans, over 50 brachiopods, 10 pelecypods, over 40 gastropods, 7 cephalopods, 4 ostracods, and 45 trilobites.

VISIT WITH THE STUDENTS OF THE EUROPEAN EARLY PALEOZOIC

BY CHARLES E. RESSER

PLEISTOCENE FAUNA FROM SEMINOLE, PINELLAS COUNTY, FLORIDA

BY W. D. MATTHEW, W. W. HOLMES, AND G. R. MEGATHLIN

In the absence of the authors, the following papers were read by title:

PRELIMINARY STATEMENT REGARDING THE TERTIARY FLORA OF MONGOLIA AND MANCHURIA

BY RALPH W. CHANEY

(*Abstract*)

The fossil plant remains of the Gobi are, so far as known, limited to silicified wood, which is present in considerable quantity in Eocene, Oligocene, and Miocene sediments. While this has not yet been critically studied, the size and twisted nature of the stems suggest conditions unsuited for tree growth. The almost total lack of leaf impressions is also indicative of a climate too dry for forests or for the preservation of leaf prints. In Manchuria, not more than 500 miles to the southeast, the writer has made considerable collections of an Oligocene flora, previously described by Florin, which closely resembles a flora of the same age in western North America and indicates a yearly rainfall of some 40 inches. The difference in climate between this part of Manchuria and Mongolia appears to have been due to the mountain range now separating them, and which during the Tertiary, as today, probably cut off most of the moisture from the monsoons on the Manchuria side of the range.

In much the same way the Rockies appear to have kept the Great Plains arid during middle Tertiary times, while the Great Basin was occupied by extensive forests. The mammalian faunas and the character of the sediments in the Tertiary of Mongolia are in general agreement with the plant fossils in indicating a climate which supported grasslands rather than widespread forests.

STRUCTURE OF THE HEAD AND DORSAL ARMOR OF DINICHTHYS PUSTULOSUS EASTMAN

BY L. HUSSAKOF

(Abstract)

Dinichthys pustulosus is of special interest among American dinichthids because of its primitive characters, early occurrence, and wide distribution (Mid-Devonic, New York to Iowa); but its detailed structure has been imperfectly known, due to scarcity of materials, specimens being usually found as isolated plates, which are generally broken and in part lost in collecting.

For years the writer has utilized every opportunity to study, photograph, or make tracings of such specimens as he could procure that added something to knowledge of this species. Among others, he had available the specimens in the Buffalo Museum, and a series, perhaps the largest extant, lent him a number of years ago by the Milwaukee Public Museum. Since no new specimens have been forthcoming for several years, the writer has decided to publish his results as far as obtained.

The paper, in full, will present illustrations from photographs or tracings of all essential anatomical details; a restoration of the head and dorsal armor, a discussion and criticism of Eastman's (1907) restoration of the head plates, and discussion and comparison with other forms.

MARINE EOCENE HORIZONS OF WASHINGTON

BY RALPH B. STEWART

REVISION OF RECENT WORK ON THE MARINE EOCENE OF CALIFORNIA

BY BRUCE L. CLARK

Following the report of the Auditing Committee that the Treasurer's accounts had been examined and found correct, the Society adjourned.

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KLER, Prof. JOHAN, University of Christiania, Oslo, Norway.
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WESTERGAARD, Dr. A. H., Geological Survey, Stockholm 50, Sweden.

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STEWART, RALPH B., Dept. of Geology, University of California, Berkeley, Calif.

CORRESPONDENTS DECEASED

KOKEN, E. Died November 24, 1912.
NATHORST, Dr. A. C. Died Jan. 20, 1921.
WOODWARD, Dr. H. Died Sept. 6, 1921.

MEMBERS DECEASED

ARMSTRONG, EDWIN J. Died Jan. 21, 1925.
BARRELL, JOSEPH. Died May 4, 1919.
BILLINGS, W. R. Died March 1, 1920.
BOSTWICK, THOMAS A. Died April, 1923.
CALVIN, SAMUEL. Died April 17, 1911.
CLARK, WM. B. Died July 27, 1917.
CLARKE, JOHN M. Died May 29, 1925.
CROZEL, GEORGE. Died October, 1921.
DERBY, ORVILLE A. Died Nov. 27, 1915.
EASTMAN, CHAS. R. Died Sept. 27, 1918.
FONTAINE, WM. M. Died April 30, 1913.
GILL, THEODORE N. Died Sept. 25, 1914.
GORDON, ROBERT H. Died May 10, 1910.
HAMLIN, HOMER. Died July, 1920.
HARPER, GEORGE W. Died Aug. 19, 1918.
HAWYER, J. C. Died May 15, 1914.
LAMBE, L. M. Died March 12, 1919.
LYON, VICTOR W. Died Aug. 17, 1919.
MATTHEW, GEO. F. Died April 17, 1923.
MOODY, W. L. Died October 9, 1920.
PROSSER, C. S. Died Sept. 11, 1916.
SEELY, HENRY M. Died May 4, 1917.
TELLER, EDGAR E. Died July 19, 1923.
VAN INGEN, GILBERT. Died July 7, 1925.
VOGDES, ANTHONY W. Died Feb. 8, 1923.
WARING, CLARENCE A. Died Nov. 4, 1918.
WILLIAMS, HENRY S. Died July 31, 1918.
WILLISTON, S. W. Died Aug. 30, 1918.
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WHITTAKER, EDW. J. Died Sept. 14, 1924.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 37, PP. 255-260 MARCH 30, 1926

PROCEEDINGS OF THE SIXTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA, HELD AT NEW HAVEN, CONNECTICUT, DECEMBER 28, 29, 30, 1925.

FRANK R. VAN HORN, *Secretary*

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JOINT SESSION WITH THE GEOLOGICAL SOCIETY OF AMERICA, DECEMBER 28

The Mineralogical Society of America held a joint session with the Geological Society of America at 2 p. m., Monday, December 28, in the Sterling Chemistry Laboratory. President William B. Scott, of the Geological Society, was in charge, and petrological papers of the Geological Society were presented. At the close of the afternoon Dr. Arthur S. Eakle, of the Mineralogical Society, delivered his presidential address, "Needed extension in mineralogic instruction," which will be published in full in the March number of the *American Mineralogist*.

SESSION OF TUESDAY MORNING, DECEMBER 29

The Mineralogical Society of America held its sixth annual meeting at Yale University, New Haven, Connecticut, in conjunction with the Geological Society of America.

At 9 a. m. the meeting was called to order by President Arthur S. Eakle in Room 2 of the Sterling Chemistry Laboratory.

On motion of the Secretary, the reading of the minutes of the last annual meeting was dispensed with, in view of the fact that they have been printed on pages 61-68 of volume 10, number 3, of the *American Mineralogist.*

ELECTION OF OFFICERS AND FELLOWS

The Secretary announced that 129 ballots had unanimously been cast for the officers as nominated by the Council. For Fellows, there were 66 votes in the affirmative for all except one man, who received 65 votes. All officers and Fellows as nominated were declared elected. It was also announced that there were 123 votes for the amendments to the By-Laws and 6 in the negative. The amendments to the Constitution were carried by a vote of 64 to 2. These amendments were printed on pages 353-354 of volume 10, number 10, of the *American Mineralogist.* The officers for 1926 are the following:

Honorary President, EDWARD S. DANA

Yale University, New Haven, Conn.

President, WALDEMAR T. SCHALLER

United States Geological Survey, Washington, D. C.

Vice-President, GEORGE VAUX, JR.

Bryn Mawr, Pa.

Secretary, FRANK R. VAN HORN

Case School of Applied Science, Cleveland, Ohio

Treasurer, ALEXANDER H. PHILLIPS

Princeton University, Princeton, N. J.

Editor, WALTER F. HUNT

University of Michigan, Ann Arbor, Mich.

Councilor 1925-29, W. A. TARR

University of Missouri, Columbia, Mo.

The list of Fellows elected follows:

CHARLES ANDERSON, Sydney, Australia.
ARTHUR F. BUDDINGTON, Princeton, N. J.
ROY J. COLONY, Columbia University, New York City.

CHARLES M. FARNHAM, Barre Plains, Mass.
ROBERT B. GAGE, Trenton, N. J.
DONNEL F. HEWETT, United States Geological Survey, Washington, D. C.
S. KOZU, Tohoku Imperial University, Sendai, Japan.
J. ORCEL, Museum d'Histoire Naturelle, Paris, France.
CLARENCE S. ROSS, United States Geological Survey, Washington, D. C.
FRANK C. SCHRADER, United States Geological Survey, Washington, D. C.
EDWARD S. SIMPSON, Perth, West Australia.
MANJIRO WATANABE, Tohoku Imperial University, Sendai, Japan.

REPORT OF THE SECRETARY

The Secretary reports that the roll of the Society now comprises 108 Fellows and 187 members, a gain of 12 Fellows and 18 members for the calendar year. Several members have been dropped for non-payment of dues. Two Fellows, Dr. E. F. Holden and Dr. F. B. Peck, have died, and a brief account of their careers will be published in the Journal. Three members—V. W. Field, G. W. Fiss, and M. L. Glenn—have also died, and notices of their demise have already been printed.

In addition to the 295 Fellows and members, there are also 114 subscribers to the *American Mineralogist;* so that there are 409 paid copies of the Journal of the Society mailed monthly. As usual, it is requested that everyone make an effort to secure additional members and subscribers. Seventy Fellows and members, as well as additional guests and visitors, attended the meeting, which, like the previous one, was the largest in the history of the Society. There were twenty-seven papers listed for presentation, which also exceeds the number for any previous meeting.

REPORT OF THE TREASURER

The Treasurer, A. H. Phillips, read his report, which showed a favorable financial balance. On motion, the report was accepted, ordered filed, and an Auditing Committee was appointed by the President. This committee, consisting of Dr. E. T. Wherry and Dr. C. S. Ross, later reported to the Secretary that they found the books of the Treasurer correct.

REPORT OF THE EDITOR

The Editor, W. F. Hunt, read his report, which, on motion, was accepted and ordered filed. The report stated that all previous records of the *American Mineralogist* have been surpassed, both as to the number of original articles published, as well as to the size of the Journal. Fifty-seven original articles were printed, which covered 382 pages and which represented work carried on in twenty-three universities and research

bureaus. The total amount of reading matter, exclusive of advertisements and index, was 448 pages, which makes volume 10 compare very favorably with other publications of a similar nature.

REPORT OF THE COMMITTEE ON NOMENCLATURE AND CLASSIFICATION OF MINERALS

The chairman, Dr. H. S. Washington, reported that, due to his absence from the country, the committee had had no meetings during the past year. Dr. E. T. Wherry, a member of the committee, presented three resolutions relating to mineral names, which were referred to the committee by the President.

MEMORIAL BIOGRAPHIES

A memorial sketch of Dr. F. B. Peck, by A. Henry Fretz, was read by Frank R. Van Horn, and a biography of Dr. E. F. Holden was given by Dr. E. H. Kraus. These will be printed in full in the March number of the *American Mineralogist*.

PRESENTATION OF PAPERS

There being no further business, the presentation of scientific papers was taken up as follows, according to the program:

DIMENSIONS OF OXYGEN ATOMS IN CRYSTALS

BY EDGAR T. WHERRY

INFORMATIONAL TYPE OF EXAMINATION AS APPLIED TO LARGE CLASSES IN MINERALOGY

BY ALBERT B. PECK

TIME FACTOR IN THE FORMATION OF SOME ARTIFICIAL MINERALS

BY ALBERT B. PECK

CHLORITE AS A POLYCOMPONENT SYSTEM

BY A. N. WINCHELL

OCCURRENCE OF THULITE AT HADDAM, CONNECTICUT

BY WILBUR G. FOYE[1]

ACCOUNT OF A RECENT TRIP TO BOLIVIA AND CHILI

BY SAMUEL G. GORDON

[1] Introduced by A. S. Eakle.

PENROSEITE AND TRUDELLITE, TWO NEW MINERALS

BY SAMUEL G. GORDON

CELESTITE AND PYRITE FROM ROCHESTER, NEW YORK

BY A. C. HAWKINS

DIRECTIONAL SENSITIVENESS IN RADIO CRYSTAL DETECTORS

BY A. C. HAWKINS

LITHIOPHILITE AND OTHER RARE PHOSPHATES FROM PORTLAND, CONNECTICUT

BY J. F. SCHAIRER

At 1 p. m. the Society adjourned for lunch and to spend the afternoon at the dedication of the new Peabody Museum.

SESSION OF WEDNESDAY MORNING, DECEMBER 30

At 9 a. m. President Eakle called the meeting to order. He announced that the Council, by virtue of power given to it by amendments to the Constitution recently passed, had elected Dr. Edward S. Dana as Honorary President of the Mineralogical Society of America, to serve for life. Later in the morning, when Professor Dana appeared to attend the meeting, the Society greeted him by standing, after which he expressed, in a few words, his appreciation of the action of the Society in electing him Honorary President.

The reading of scientfic papers then proceeded according to program:

PRESENTATION OF PAPERS

APPLICATIONS OF COLLOID CHEMISTRY TO MINERALOGY

BY LLOYD W. FISHER

MINERALS FROM THE NEW NEPHELINE-SYENITE AREA ON FRENCH RIVER, ONTARIO

BY T. L. WALKER AND A. L. PARSONS

ZEOLITES AND RELATED MINERALS FROM LAKE NIPIGON, ONTARIO

BY T. L. WALKER AND A. L. PARSONS

OXIDATION OF ARSENIDES OF COBALT, IRON, AND NICKEL

BY T. L. WALKER

ADDITIONAL DATA CONCERNING THE PRESERVATION OF MINERALS

BY A. L. PARSONS

SUGGESTIONS CONCERNING USE OF SPECIES NAMES IN THE GARNET, AMPHIBOLE, PYROXENE, AND TOURMALINE GROUPS

BY FRANK R. VAN HORN

CARNOTITE FROM COLORADO AND ROSSITE, A NEW CALCIUM VANADATE FROM UTAH

BY FRANK L. HESS AND W. F. FOSHAG

DOUBTFUL MINERAL SPECIES AS ILLUSTRATED BY "FAROELITE"

BY A. N. WINCHELL

ORIGIN OF PEGMATITE MINERALS

BY W. T. SCHALLER

ORIGIN OF GRAPHIC GRANITE

BY W. T. SCHALLER

OPACITY

BY ERNEST E. FAIRBANKS

Read by title.

CURTISITE, A NEW ORGANIC MINERAL FROM SKAGGS SPRINGS, SONOMA COUNTY, CALIFORNIA

BY FRED E. WRIGHT AND E. T. ALLEN

STRAIN STRUCTURE IN QUARTZ FROM DUCKTOWN, TENNESSEE

BY PAUL F. KERR

CRYSTALLINE COMPOUNDS IN THE SYSTEM SODIUM METASILICATE-CALCIUM METASILICATE-SILICA

BY N. L. BOWEN AND G. W. MOREY

STRUCTURE OF HIGH-QUARTZ AND THE POSSIBLE NATURE OF SILICATES

BY RALPH W. G. WYCKOFF

SIMPLE MODEL FOR ILLUSTRATING CRYSTAL STRUCTURES

BY RALPH W. G. WYCKOFF

VOTE OF THANKS

The last paper was finished at 12.55 p. m., after which Dr. E. T. Wherry moved that the thanks of the Society be extended to the local committee, and to the President and Trustees of Yale University, for their kindness and hospitality. This was seconded and unanimously adopted, after which the Society adjourned.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 37, PP. 261-278 MARCH 30, 1926

GEOLOGICAL CLIMATES

PRESIDENTIAL ADDRESS BY W. B. SCOTT[1]

(*Read before the Society December 28, 1925*)

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HISTORICAL STATEMENT

Very early in the history of our science it became evident that the earth had passed through great climatic changes, and the effort to find an explanation of these changes which should be adequate and satisfactory has never ceased till this day. There has of late been a revival of interest in this problem, and many new works on the subject have appeared in this country, as well as in England and Germany.

One great obstacle in the way of finding convincing explanations for past climatic changes was the fact that, since weather records have been kept, no definite changes of climate could be detected, though it was admitted that those records covered too short a period of observation to be at all decisive. Some historians, notably Gibbon, in his famous *Decline and Fall of the Roman Empire*, have attempted to prove the reality of climatic changes within the historic period, especially in central Europe; but the evidence is not satisfactory. The appeal to agencies still in operation, the study of which constitutes dynamical geology, would seem, therefore, to be impracticable.

The uniform distribution of the vegetation of the Coal Measures over immense areas, involving very great differences of latitude, is of itself a problem that has not been satisfactorily solved, even yet. One of the most eloquent of Hugh Miller's descriptive passages is his imaginative

[1] Manuscript received by the Secretary of the Society March 3, 1926.

reconstruction of the climate and weather conditions which obtained in the great bogs and marshes of Carboniferous time. As coal is composed chiefly of carbon, which had been derived from the atmosphere through the agency of living plants, it was taken for granted at that time that all of it had existed in the atmosphere simultaneously in the form of carbon dioxide; but this would have had very remarkable consequences, many of which were not known in Miller's day. Miller does not seem to ascribe the climatic conditions to the atmospheric composition, since he gives no discussion of the causes of climatic change; but the juxtaposition of the supposed facts is suggestive.

Until Louis Agassiz propounded his Glacial theory in 1840, it was assumed that the Recent epoch, or present time, was, climatically speaking, something altogether exceptional in the history of the earth, as before that, according to the universally accepted belief of the time, there had been throughout the ages an unbroken succession of mild and genial climates, without polar accumulations of ice and snow and with no well-marked distinctions of latitude. Agassiz's conception introduced an entirely new factor into the problem and was, indeed, so novel and revolutionary in character that it was long rejected by most geologists; and even so late as 1895 Sir Henry Howarth, a trustee of the British Museum, stigmatized it as "the Glacial Nightmare." The theory made but slow progress toward general acceptance until, eventually, the evidence became so cogent that nearly all geologists were converted to it. Nowadays it is taken as a matter of course and is taught in all the elementary textbooks. Thus it became necessary to account for a time of exceptional cold, though this was a matter of debate among those who accepted the Glacial hypothesis.

Some of the most eminent geographers maintained that the Glacial epoch had been due to a greatly increased snowfall, bringing about accumulations in the winter which could not be melted in the summer, rather than to any great decrease of temperature. Thus it was uncertain just what the problem consisted of and just what it was that called for explanation. Gradually, however, the proofs of lowered temperature rather than of increased precipitation seemed irresistible, and now everyone accepts that view of the problem. It is not necessary to assume any increase of snowfall to account for glacial conditions; but, on the other hand, temperature changes would of themselves necessarily have caused great alterations in the distribution of the rainfall. For example, the cold of Pleistocene times extended the rain-belt so far southward as to make the now arid Great Basin a region of moist climate, supporting immense fresh-water lakes, while the rise in annual temperature which

caused, or at least accompanied, the disappearance of the continental ice-sheets restricted the rain-belt to its present limits.

After the general acceptance of Agassiz's hypothesis, it was thus believed that, through much the greater part of its recorded history, the earth had had a mild, genial, and almost uniform climate, without definite climatic zones; that this condition had been broken by the cold of the Pleistocene, the partial recovery from which had led to the present order of things.

Climates of the Earth's Past

We now know, however, that the problem is much more complicated than would appear from this brief statement. In 1879 Blanford reported Permian glaciation from peninsular India—an announcement which was received with complete skepticism on the part of most European geologists, though followed by similar reports from South Africa, Australia, Brazil, and Germany. In 1905 I had the privilege of taking several geological excursions in South Africa, which had been arranged for the meeting of the British Association for the Advancement of Science, under the direction of Mr. A. W. Rogers, chief geologist of Cape Colony, and of Messrs. Hall and Kynaston in the Transvaal.

One object which was of especial interest and importance to all of the visitors at that time was an examination of the evidence for the great Permian ice-cap, and the geological party contained such eminent students of glaciers as Professors Penck of Berlin, Sollas of Oxford, Coleman of Toronto, and Davis of Harvard. The distinguished Swedish geologist, Professor Sjögren, who was also of the party, told me that few continental geologists were prepared to accept the hypothesis of Permian glaciation. Yet the field demonstrations given us, especially at Riverton, on the Vaal River below Kimberley, were convincing to all of us, without exception. The boulder clays and moraines and the ice-pavements, with their characteristic polishing and striation, their hummocks and roches moutonnées, were every whit as complete evidence of glaciation as were the corresponding Pleistocene phenomena at home, and of precisely the same nature.

But even the Permian (or Permo-Carboniferous, as the English geologists prefer to call it) glaciation was not the only ice-age of long past epochs. There is evidence, as yet incomplete, of glaciataion in the Carboniferous of North America. The Bokkeveld of South Africa, a marine Devonian formation, contains large, facetted, polished, and striated pebbles and cobbles of unmistakable glacial origin, but ice-pavements and boulder clays of this period have not yet been found. The Silurian

moraines of Norway were probably of local origin and do not indicate any widespread climatic changes.

Very extensive boulder beds, observed in China and Australia and originally referred to the Cambrian, are now placed in the later pre-Cambrian eras, while the tillites described by Professor Coleman in Ontario and those of British Bechuanaland in Africa are of a still more ancient date. Thus we have the remarkable fact that glaciation on a continental scale has repeatedly occurred, not less than five times and perhaps more, in the recorded history of the earth. These recurrent climatic phenomena can not be called rhythmical because, so far as we can judge, the intervals between them were not of similar length, features which render the problem of causation all the more complex and difficult.

So far as the ancient glaciations are concerned, the distribution of the ice is still a matter of uncertainty, because obviously only a relatively small part of the glacial deposits and ice-pavements could have been preserved, in accessible positions, from such long-distant times. These ancient glaciations, too, add greatly to the complexity of the problem because of characteristics peculiar to themselves. For example, in South Africa, and perhaps also in Brazil, the movement of the Permian ice was from north to south, from the equator poleward, the opposite of what we should have expected it to be. Furthermore, the enormous thickness of the boulder beds, 1,000 feet or more, called the Dwyka conglomerate, fairly staggers the imagination when one compares it with Pleistocene moraines. The occurrence of great boulder beds in peninsular India, so near the equator, is a very puzzling circumstance, which some climatologists believe can be explained only by a shifting of the earth's poles.

Because of those uncertainties, it will be advantageous to confine our attempts at explaining glacial climates to the Pleistocene, because the evidence is still so very extensively and perfectly preserved that the distribution of the Pleistocene ice-sheets and mountain glaciers can be determined with a certainty which can not be attained in the more ancient periods of ice-action. If we can find a satisfactory explanation of the climatic phenomena of the Pleistocene, we shall not have far to seek for an explanation of the more ancient ice-periods.

There would seem to have been no glaciation on a continental scale between the Permian and the Pleistocene. Throughout the Mesozoic and most of the Tertiary periods, indications of climatic zones are obscure and doubtful, and there can have been no great accumulation of ice and snow at the poles. The Jurassic sandstones of the now utterly desolate

Antarctic continent have yielded Cycad leaves much like those of contemporary Great Britain, and the Arctic fossil floras of Greenland and Alaska clearly demonstrate that, so late as the Eocene at least, these polar lands had luxuriant forests of large trees of the kinds familiar to us in temperafe latitudes—a fact which indisputably proves the prevalence of much milder climates. That the Arctic regions were cooler than the area now covered by the United States is indicated by the absence of large reptiles, of palms and other subtropical forms from the far north, while they occur from Idaho and Montana southward; and the Eocene flora of the southeastern coastal plain, so beautifully reconstructed by Professor Berry, demonstrates a far warmer climate than that of today, though not properly to be called tropical.

In the interior of the continent, in the region of the northern Great Plains, there is a distinct climatic change between the Eocene and Oligocene, palms and large crocodiles disappearing from the area where they had been prevalent and abundant since the Middle Cretaceous. The change, though definite, was not extreme, and may well have been due rather to an increased altitude than to any general modification of climate. The Miocene flora of central Colorado was, except for the absence of palms, much like that of the northern Gulf region at present. The gradual refrigeration which marked the climatic transition from the warm Miocene to the cold Pliocene is best registered in Europe. The German lignites, or brown coals, of Miocene date, have preserved a very full representataion of the plants. In the older lignites the flora is that of the Mediterranean lands, with palms and other warm temperate trees, while the upper lignites of the same region indicate principally coniferous forests. The marine Pliocene beds in the east of England have beautifully recorded the oncoming cold. In the lower strata those beds contain 5 per cent of Arctic shells, a proportion which rises to 60 per cent in the upper strata.

In the far north the Pliocene climate must have been severe, as is indicated not only by the Arctic species of shells just referred to, but also by the Pleistocene mammals, which descended to comparatively low latitudes before the advance of the ice. The familiar instances of musk-oxen in Kentucky and Arkansas, caribou on Long Island Sound, seals and walruses on the coast of Georgia, mammoths and reindeer in the south of France, lemmings in Portugal, all show a complete Arctic assemblage of mammals, both terrestrial and marine. These could not have been developed over night; they must have passed through a long period of adaptation to a climate which was steadily growing colder. The onset of glacial conditions found a fully adapted fauna of Arctic

mammals, with nearly uniform circumpolar distribution, though some forms, such as the woolly rhinoceros, were confined to one or the other continent, for reasons that we can not even conjecture.

The interpretation of the Pleistocene deposits, even after their ice-made character had been generally acknowledged, led to a long-drawn-out debate. Was the Glacial epoch single or multiple? That the ice had been subject to many episodes of advance and retreat was admitted; the question was: Were these episodes mere fluctuations in the extent of the ice-sheets, or were there actual interglacial times, when the ice altogether disappeared and the climate was greatly ameliorated? Time fails me to give any but the most superficial reference to this famous discussion. Sufficient to say that it is the all-but-unanimous opinion of students of this problem that there were several truly glacial and interglacial stages when there were great climatic changes, and some, at least, of the interglacial times were actually warmer than the present. Very convincing evidence to this effect has been found on the north shore of Lake Ontario, near Toronto. There a series of stratified, water-laid clays, contained between two boulder beds, is divisible into an upper and a lower series. The lower and older series has many fossil plants which indicate a flora such as now occurs several hundred miles to the south, in Kentucky and Tennessee. Of the upper series, the fossils resemble Labrador species and eloquently indicate the return of the cold, culminating in the ice-sheet which deposited the upper boulder beds. Professor Coleman has reported that on the shores of Hudson Bay large forest trees are found between two ground moraines, trees which are indicative of milder climatic conditions than those of Recent time in that latitude.

Similarly, the interglacial mammalian fauna which occurs at Afton, Iowa, is decidedly suggestive of a warmer climate than the present for the region involved. In this case, however, the evidence is less convincing, for the habits of extinct species of mammals can only be conjectured, and, as in the famous case of the Siberian mammoth, some ludicrous mistakes have been due to inferences concerning the climatic adaptations of extinct species, reasoning from the distribution of their existing allies. Whether all the interglacial stages were characterized by a warmer climate than that of modern times, it is not yet possible to determine for lack of the necessary fossiliferous deposits.

In any satisfactory theory of the Pleistocene climates we must account for world-wide climatic change, or series of changes, so that local causes are inadequate; for in all of the continents of both northern and southern hemispheres there is proof of the great extension of glaciers in that

period of time. Inasmuch, however, as the southern hemisphere is chiefly a region of sea, with but a relatively small amount of land, climatic fluctuations in that hemisphere have been and still are much less extreme than in the northern, where there is so large a proportion of land. This is an explanation of the fact that in the south temperate zone Pleistocene glaciation was much less extreme than in the corresponding northern belt. This southern glaciation, as is so well exemplified in Patagonia, was chiefly confined to a great extension of the mountain glaciers rather than to the formation of continental ice-caps, such as appeared in Europe and on so vast a scale in North America.

Penck has made it very probable that all over the world the snow-line was lowered approximately 4,000 feet below its present altitude—an amount which he first deduced from his studies in the Alps and subsequently confirmed by very widespread observations in other continents. Even in the tropics the same rule would seem to apply. Mount Kilimanjaro, the highest mountain in Africa, which stands very near the equator (3 degrees south latitude), still has snow-fields and glaciers near the summit, while the unmistakable ice-marks of polishing and striation extend more than 5,000 feet below the present limit of the glaciers—a very different thing from the snow-line. To produce such climatic conditions, Penck has calculated that a lowering of the annual average temperature of about 9 degrees Fahrenheit below the existing standard would suffice. That amount, 9 degrees Fahrenheit, is all that stands between us and a recurrence of glacial conditions.

In brief, therefore, what we must account for is the long continuance, throughout the Mesozoic and earlier Tertiary times, of genial, nearly uniform conditions of climate, with zones only obscurely demarcated. There was then, and probably always has been, a difference of temperature between the equator and the poles, as is indicated by the distribution of fossil floras, but a difference far less in amount than that which now obtains. In the latter half of the Tertiary period began a slow and gradual refrigeration, which had brought severe conditions in high latitudes in the early Pliocene—conditions in which the typically Arctic fauna of mammals had been differentiated. The increasing cold finally culminated in the widespread glaciation of the Pleistocene; but this was itself highly complex, from the climatic point of view. Within a short space of time, as geological time is measured, there were many extreme fluctuations of climate, four or more glacial, alternating with interglacial stages. It would be going beyond the evidence to say that in all the interglacial stages the climate was milder than at present, but it may have been so in all, and certainly was in some. Finally, the conditions

were once more ameliorated, bringing about the present order of things.

This is far from being a complete statement of the problem of geological climates, or even of the temperature factor in climates, but in this abbreviated and simplified form it will suffice for our present purposes. The solution of the problem in this form will offer quite sufficient difficulty for an evening's consideration. Only a brief mention of the cognate climatic factors—moisture, precipitation, and prevailing winds—is permissible because of the limitations of our time.

Theories to explain Glacial Epochs

Wherever it is feasible, I have always thought that there is an especial charm in presenting scientific theories historically, as this method records the progress of discovery and interpretation, the modifying of view necessitated by the discovery of new facts, and reveals the steps by which we have so gradually and laboriously advanced from the known into the unknown.

In this manner we should learn that more than half a century ago hypothetical explanations of climatic change were put forward which, essentially and in principle, were almost exhaustive of the known possibilities. Sir Charles Lyell sought the explanation in widespread and radical changes in the distribution of land and sea. Taking the present continents, he showed that, without any alteration of size, shape, or altitude, great climatic differences could be brought about by grouping these land-masses, first, as closely as possible around the equator and, subsequently, around the poles. The Vienna geologists, supported by the eminent astronomer, Father Secchi, maintained that the earth's axis, and with it the poles, had been shifted, bringing certain regions which were formerly Arctic into the temperate zone, and thus changing their climate very completely.

Dr. James Croll, of the Scottish Geological Survey, published his *Climate and Time* in 1875, a book which speedily became famous. Croll called attention to the fact that the size and shape of the earth's orbit were not constant, but subject to change, which resulted in periods of maximum and minimum eccentricity. He contended that the hemisphere which had its winter in aphelion during a time of maximum eccentricity would pass through a period of glaciation. On this hypothesis glacial periods would recur alternatingly between the northern and southern hemispheres and rhythmically every 12,500 years.

I have not been able to learn who it was that first suggested the internal heat of the earth as the cause of the former mild and uniform cli-

mates, and the gradual loss of the earth's heat by radiation as having brought about the refrigeration of climate which has led to the present order of things. This conception is nearly as old as geology or the Nebular Hypothesis of Laplace. In modified form it has lately been revived by Dr. Knowlton.

Finally, I may mention Lord Kelvin's[2] suggestion that the cause of climatic changes on the earth should be sought in fluctuations of the sun's activity—a suggestion which seemed to be made obvious by the connection between the weather and the maxima and minima of the sun-spot periods. Among geologists it is, perhaps, Professor Penck who has most strongly championed this view, for it is he who has most clearly brought out the universal nature of the climatic changes in the Pleistocene.

Though the historical method of approach is the more interesting and, perhaps, the more instructive, it is in the interests of brevity and lucidity to deal with the various hypotheses which have been propounded to explain the climatic changes which have occurred in the recorded history of the earth, in a more systematic manner. The subjoined table presents a classified arrangement of the principal hypotheses which have been offered in explanation of the problem of climate. Obviously, it will not be practicable to devote more than a very brief time to the discussion of the various hypotheses.

I. Terrestrial causes.
  A. The earth as a whole.
    1. Changes in the eccentricity of the orbit.
    2. Shifting of the earth's axis.
    3. Shifting of the earth's exterior on the interior.
    4. The internal heat of the earth.
  B. Atmospheric factors.
    1. Variation in the proportion of carbon dioxide;
    2. In the amount of suspended volcanic dust.
  C. Oceanic factors.
    Variations in salinity.
  D. Topographical factors.
    Changes in the area, altitude, and disposition of the land-masses.
II. Cosmical causes.
  A. Passage through cold regions in space.
  B. Variations of the sun's activity.

As the table indicates, the methods of explanation fall into two prin-

[2] The hypothesis of solar change as causing climatic changes on the earth was adopted by Penck. Prof. H. F. Reid kindly pointed out to me the fact that the suggestion was originally due to Lord Kelvin.

cipal categories: (1) the terrestrial, in which the source of change arose on the earth itself, and (2) the cosmical, in which the cause lies outside of the earth, or even outside of the solar system. Of the terrestrial agencies of change, we may make two groups, (*a*) those which affect the earth as a whole, and (*b*) those which are more or less local and partial in their operation.

A. 1. Croll's hypothesis was published when I was an undergraduate and just beginning the study of geology, and I can well remember the enthusiasm with which it was received in this country. "At last," we said, "the climatic mystery, which has been troubling us for so long, has found a solution." But the enthusiasm was short-lived, for its requirement of an ice age at intervals, for each hemisphere, of 25,000 years was found to be incompatible with the ascertained facts of geological history. Probably Dr. Croll himself would have been aghast at the number of Glacial periods which the earth must have passed through, according to his supposition. The ten, or at most twenty, million years which, in 1875, were allowed for the age of the sun have been almost indefinitely extended by the later physical discoveries. Had ice ages occurred with the rhythmical regularity which Croll postulated, the northern and southern hemispheres must each have had some 40,000 of them, which does not seem likely.

A. 2. Shifting of the earth's axis and the concomitant changes in the position of the poles are by most astronomers declared to be impossible. Into this astronomical problem we need not enter, for no position of the poles which has yet been suggested would get rid of the necessity of admitting climatic change. This hypothesis and the following one are not, strictly speaking, attempts to explain climatic changes, but to account for the distribution of fossil floras and faunas without assuming important changes in the earth's atmospheric temperatures.

A. 3. A shifting of the earth's outer shell on the interior is a hypothesis much like the preceding, but differs in the suggested mechanism of change. Thus, Wegener suggests that the vast Permian glaciation in the southern hemisphere was due to the junction of the southern continents around a pole in the Indian Ocean, and that they have since drifted apart. But this suggestion, even if true, would not account for the facts; as Lake has pointed out, Permian ice-sheets covered northern Baluchistan, which, according to the hypothesis, would then have been in the tropics. Concerning the possibility of the shift itself, Jeffreys remarks: "A displacement of this type would produce important climatic changes; but so far no agency capable of producing it has been suggested."

A. 4. It was long supposed that the ancient geniality and uniformity which, for such vast stretches of time, characterized the earth's climate were due to the internal heat of the globe, and the present severe climates of high latitudes have been brought about by the reduction of the internal heat by radiation. Aside from the question raised by the phenomena of radioactivity, whether the earth has actually lost heat (Joly even suggests that it may be gaining, rather than losing), this hypothesis postulates a continual change in one direction and fails to account for fluctuations of climatic conditions. Since the formation of a solid crust (assuming that the globe was once fluid) the very low conductivity of the rocks must have prevented the internal heat's having much effect at the surface.

"The surface temperature of the earth must have been almost wholly maintained by solar radiation practically ever since it became solid at the surface, and certainly throughout geological time. Conduction from the interior is in comparison quite unimportant" (Jeffreys).

B. The foregoing hypotheses all deal with the solid earth as a planetary unit, using the term "solid" without prejudice to the conception of possible fluid portions of the interior. We may next consider the explanations which find the causes of climatic change in modifications of the atmosphere. It is universally understood that the atmosphere has a blanketing effect, permitting the direct rays of the sun to pass through it freely, but opaque to the dark heat reflected from the ground. In this way the air acts like the glass in a cold frame, which Tyndall poetically called "a trap to catch a sunbeam." This blanketing effect is least in thin, dry, and pure air and is greatly increased by the presence of vapor of water and carbon dioxide in the atmosphere. It has seemed a natural inference that a large augmentation of the amount of carbon dioxide present in the air would so raise the blanketing effect that genial climatic conditions would be produced, even in the polar regions. There is, however, a fatal objection to this inference revealed by experiment, namely, that the amount of carbon dioxide already normally present in the atmosphere exerts nearly the maximum blanketing effect, and a large increase in the amount of the gas would not produce a corresponding rise of temperature.

B. 2. A screen of volcanic dust remaining long suspended in the upper atmosphere, as did the fine dust after the great eruption of Krakatoa in 1883, might so cut off the sun's heat as to cause a refrigeration of the earth's surface temperature, and such a screen has actually been appealed to as a cause of glacial climates; but the supposed cause seems

neither actual nor adequate. There is nothing in known geological history which would justify us in supposing that such masses of volcanic material, diffused over the whole earth, were ever maintained for tens or hundreds of thousand years. The geological periods in which vulcanism was most active, such as the Ordovician and the Devonian, were not those of widespread glaciation. Indeed, the opposite conception is held by those who find the explanation of higher air temperatures in the greatly increased content of carbon dioxide; they maintain that the most actively volcanic periods were the warmer ones, the carbon dioxide being supplied by the volcanoes.

C. Ocean currents are familiar means of modifying climates, the warm and cold currents having a marked effect on the air with which they come into contact. It has been maintained that variations in the density of sea-water, due to changes of salinity, would greatly modify the system of oceanic circulation. To this it may be objected that the great ocean currents are due to prevailing winds, and so long as the system of winds remained unchanged, variations in the density of the water could have little effect on the currents.

D. Changes in the size, distribution, and altitude of the land-masses were, as we have already seen, first invoked by Lyell to explain the earth's vicissitudes of climate, and of late there has been a strong revival of interest in causes of this nature, and three quite recent books appeal to them as all-sufficient for the purpose. Mr. C. E. P. Brooks has of late years (1922) published a very valuable and suggestive little book, *The Evolution of Climate*, which is devoted to this thesis. Professor Berry, from a study of the fossil floras of North America, reaches the same conclusion, as does substantially Professor Ramsey, of Helsingfors, who published his observations and deductions in volume 64 of the Geological Magazine. To say the least, it is a remarkable coincidence that so many and so widely separated investigators should have reached the same conclusion from somewhat different kinds of evidence. In his lately published book, *The Earth, its Origin, History, and Physical Constitution* (1924), Dr. Harold Jeffreys, of Cambridge, devotes a considerable part of the appendix on Theories of Climatic Variation to an examination and criticism of the work of Brooks. It will serve our purpose excellently to quote a few extracts from Jeffreys' review:

"In this way Brooks is able to show that more oceanic conditions, which actually existed, are quantitatively able to account for the mild climate of the Eocene period. A general elevation of the land proceeded throughout the Tertiary era, and when the Scandinavian highlands and the Rocky Mountains reached the snowline an ice-sheet commenced to form. . . . The actual

events during the Glacial period and afterwards agree closely with Brooks's inferences. In particular, some sand dunes in north Germany, formed at this time, have their tips pointing to the west instead of the east, showing that the prevailing wind there at the time was from the east. This is exactly what would be expected from the presence of the Scandinavian ice-sheet, which would produce . . . east winds over Germany. In many other parts of the world striking agreements are found. . . . Brooks's theory is, therefore, a very substantial contribution to our understanding of climatic change; but it does not furnish a complete explanation. . . . It appears as if the later stages, at least, of the elevation of the mountains took place under conditions when the snowfall was inappreciable, and that the ice-sheet did not begin to form until some further change of climate, not attributable to the mountains, had supervened. The Cambrian, Ordovician, and Silurian folds, again, must have raised mountains quite comparable to those of the Tertiary, but do not appear to have been followed by glaciation on anything like the same scale, again suggesting that mountain formation, though it may be a necessary preliminary to glaciation, is not a sufficient condition for it."[3]

An elaboration of this same conception sees in the many climatic fluctuations of the Pleistocene an isostatic response of the earth's crust to the load imposed on it by the immense accumulations of ice. The ice-sheets were established, it is supposed, when the continents had risen to a high level and, under the enormous load of ice, they again sank to an altitude at which the ice melted and snowfall was no longer sufficient to maintain the ice-caps. Freed from its load, the land again rose to a height at which the ice was again formed, only to sink once more under the renewed load.

Many observations have been made which strongly suggest that the relation between loading of the land with ice and subsequent depression is more than coincidence. But if that were all, why did the process cease? Why was the last melting of the ice not followed by a renewed elevation of the land? It may be said that not time enough has elapsed since the last disappearance of the ice, and that we are slowly but surely advancing to a new Glacial epoch. Perhaps so, but there is no sufficient evidence of a universal rise of the land in high latitudes, such as would be called for on this hypothesis. Furthermore, if diastrophic movements were the sole cause of the glacial and interglacial alternation, we should have no explanation of the fact that in some, at least, of the interglacial stages the climate was warmer than at the present time. Some additional factor is called for.

I can not but agree with Jeffreys in his conclusion that, while diastrophic movements of the earth's crust are a very real cause of climatic change, they are insufficient to account for the accepted history of the

[3] Jeffreys: Op. cit., p. 265.

vicissitudes of climate through which the earth has passed. The lowered temperature of the Pleistocene was a world-wide phenomenon and is registered in all the great land-masses of both northern and southern hemispheres. Even in the tropics the ice limit was several thousand feet below that of the present day. We have no satisfactory proof of a correspondingly universal upwarping of the lands, and therefore the diastrophic hypothesis, as it may be called, is inadequate as the sole explanation of the facts.

It should be added that a great deal remains to be learned concerning the Pleistocene glaciation of the southern hemisphere, for little intensive study has as yet been devoted to the problems involved. It is not definitely known, for example, whether glacial and interglacial alternations characterized the continents of the southern as they did those of the northern hemisphere, nor how many Glacial stages there were, or if, indeed, there was more than one. Obviously, a complete theory of the Pleistocene climates can not be formulated until much more has been learned regarding the southern continents in that epoch.

II. So far we have dealt entirely with supposed agencies of climatic change which have affected the earth only, either as a whole or in part. In the second principal category of hypotheses the causes of climatic change are sought for in agencies entirely outside of the earth, and therefore cosmical rather than terrestrial. Croll's famous theory might almost as well be put in the cosmical as in the terrestrial class, though it deals solely with the earth.

A. It has been suggested that the solar system, in its known swift passage through space, traverses regions of different temperature, which would produce a corresponding modification of the earth's climates. This purely fanciful conception need not detain us, for space can have no temperature, which is a property of matter. That the earth could have received an appreciable amount of heat from some luminary other than the sun would involve so near an approach to another star as to upset the equilibrium of the solar system.

B. By a process of elimination we seem to be shut up to the conclusion that we must look for the primary causes of changes in the earth's climates in the sun itself, as originally suggested by Lord Kelvin. As we have just seen, the various terrestrial agencies which have been called on to explain these changes are inadequate of themselves, while changes in the sun would have universal effects. The connection between the sun-spot cycles and terrestrial weather has long been recognized, and the Smithsonian observatory, under the direction of Dr. Abbot, has shown that variations in solar radiation do actually occur, and to a surprising

amount, from day to day, as well as through longer periods. The observing stations have been operated in regions of different climates and altitudes, so as to do away with the confusing effects of the earth's atmosphere. The work is still in progress, and Dr. Abbot has lately been in Africa searching for a satisfactory site on which to place another control station, and we may hope soon to have a body of established facts concerning solar activity which will be most useful in the solution of our problem. The manner in which solar changes operate on the earth is a very complicated one, and if these changes are of no very great amount they would produce different effects in the various climatic zones. This has been well brought out by Mr. Clayton in a paper read last April before the National Academy of Sciences.

As Jeffreys has pointed out, any hypothesis of this type is very difficult either to prove or to disprove; but we do know that the earth's temperature depends on the sun, and that the sun's activity is variable—not a long, slow decline. Hence arises the probability that solar changes are the principal cause of the earth's variations of climate. This conclusion does not preclude the acceptance of the terrestrial agencies as modifying the effects of solar change. Assuming the effectiveness of the latter, the Pleistocene history of the southern hemisphere well illustrates such modifying effect. The vast area of the seas and the relatively small land surfaces produce an oceanic climate in which extremes of heat and cold are rare. All down the west coast of southern Chile and Tierra del Fuego, almost to Cape Horn, we find an evergreen rain forest of deciduous trees, most of which belong to a single species of the southern beech (*Nothofagus*). In this region there is little difference between winter and summer; the weather is always cold, though never extremely so. In this instance the modifying effects of solar changes are produced by the distribution of the marine and continental areas. In the northern hemisphere, there is much reason to believe, diastrophic movements, both the orogenic folding and the epeirogenic warping of broad areas, have had an important bearing on the effects of solar changes, now opposing and reducing those effects, now assisting and increasing them.

Variations in Rainfall and their Causes

The second great factor in the determining of climates is moisture and its resulting precipitation in the form of rain or snow. Even more than temperature, precipitation is affected by topography and prevailing winds. High mountain ranges, which cut off moisture-laden winds, may throw a "rain-shadow" far across the continent, as do the ranges of the

Pacific Coast region. The remarkable monsoons of the Indian Ocean, a reversible system of winds, bring the rains to India when blowing from the southwest. Many similar instances of the effects of topography and prevalent winds might be mentioned, if it were worth while to do so; but these are well understood and it is not necessary to recapitulate them.

Evidences of arid climates in ancient geological times where now are regions of pluvial conditions are abundant, and such evidences are for the most part independent of fossils and are contained in the rocks themselves. Beds of gypsum and rock-salt are indicative of aridity, for they are accumulated in salt lakes, which can not be maintained in regions of normal rainfall; and the distribution of such deposits in time and space, their geological and geographic arrangement, frequently enable us to demarcate the regions of special aridity. No doubt there were many others of which we do not know, the proofs of which have been swept away by denudation. The changes from pluvial to arid conditions, and *vice versa*, would seem to have been local in some instances, of immense geographical extent in others.

The Ordovician of Siberia and the Lower Carboniferous of eastern North America were, so far as we can judge, instances of locally restricted changes to more or less arid conditions, while nearly the whole of the Permian and Triassic periods show a belt all around the northern hemisphere of extreme aridity. Under the north German plain lies a vast body of rock-salt of unknown thickness, for none of the very deep bore-holes which have been put down reach the bottom of the salt. Making a reasonable allowance for the thickness of the salt-body, it has been estimated that it represents the evaporation of a body of sea-water three times as great in cubic content as the Mediterranean Sea. The whole trans-Mississippian region of North America was a desert in Permian-Triassic times, though perhaps not so extremely arid as central Europe; and even the eastern part of the continent, north of Virginia, was sub-arid—at least most students of the Newark formation are led to that opinion by the character of the sediments.

If, now, we plot on a Mercator's chart the known arid regions of the Permian and Triassic periods, we are immediately reminded of the desert zones which in both hemispheres encircle the earth at the present time. These zones of desert are the trade-wind belts, where the equatorial outflow of heated and expanded air descends once more to the earth's surface. Such descending currents, being adiabatically warmed through condensation, are always dry, and hence the zone of desert where they impinge on the land. In both northern and southern hemispheres the temperate zones are areas in which the prevailing winds are

westerlies, blowing some 80 per cent of the time from some westerly quarter. Equatorward from the westerlies, in both hemispheres, lie the "Horse latitudes," belts of light, variable winds, and beyond these again are the trade-wind belts. Between the northeast and the southeast trades is the equatorial belt of calms. The whole tropical wind system, with its five zones, swings north and south with the sun in its apparent path between the solstices, so that certain regions have the trade winds in summer but not in winter. Such areas are southern California and the southern parts of the great Mediterranean peninsulas of Europe—the Iberian, the Italian, and the Balkan—and these all have nearly rainless summers, the precipitation of the year being concentrated in the winter.

If we may assume that during most of the Permian and the whole of the Triassic periods there was such an increase of solar activity as to raise the surface atmospheric temperature some 8 degrees or 10 degrees Fahrenheit above the present annual averages, this would have the effect of displacing or extending the trade-wind belt some hundreds of miles north of its present position (note well, confining our attention to the northern hemisphere), and with it the desert zone of the northern continents. That such would be the actual effect of a moderate rise of atmospheric temperature is made very probable by the converse effect of lowered temperature in the Pleistocene, to which reference has already been made. During the times of principal ice extension, precipitation was so increased in what is now the arid and semi-arid West that immense fresh-water lakes were established in the Great Basin, and almost every valley in the Colorado Rockies and in the Sierra Nevada down to middle California was occupied by a great stream of ice.

It may not seem legitimate to assume that the existing wind system extended so far back into the distant past; but, as a matter of fact, this system, aside from local currents, is, in Davis's phrase, "planetary," and is determined by the earth's relations as a planet. So long as the earth rotates on its axis and revolves about the sun; so long as its axis remains oblique to the plane of its orbit, producing differences of temperature in different regions, so long must the general system of winds remain what it is now and what we have every reason to believe it has always been from the beginning of land and sea. Raising and lowering the atmospheric temperature will undoubtedly shift the position of the wind-belts, but will not affect them otherwise.

We have direct proof that in the Pleistocene, at least, the system of winds was substantially the same as now. Every one is familiar with the fact that the western side of Europe has a much milder climate than

the Atlantic coast of North America, with no such extremes of temperature. Great Britain and Labrador, Norway and Greenland, New York and Naples, have much the same latitude. The difference in climate, which amounts to 10 degrees of latitude, is due to the westerly winds, which reach Europe from the sea, eastern North America from the land. The same climatic difference, and for the same reason, obtains between the Atlantic and Pacific coasts of North America and between the American and Asiatic shores of the Pacific. During the maximum glaciation in the Pleistocene the extension of the northern ice-caps was to latitude 50 degrees in Europe and 40 degrees in eastern North America, just such a difference as we find today.

The studies of Professor Huntington have satisfied most geographers of the reality of the desiccation, which has been in progress for the last two thousand years, from central and western Asia to California. The desiccation has not been uniformly progressive, but subject to wide fluctuations, though the algebraic sum of the fluctuations is greatly increased dryness. Whether this increasing aridity can be correlated with rising temperature is not yet known, but it must be said that we know no cause of desiccation except greater heat.

I should, perhaps, apologize to the members of the Society for selecting as the topic of this address so hackneyed a problem as that of geological climates, in which it is hardly possible to suggest anything that has not been suggested many times before. It is, indeed, a threshing over of old straw. Yet there has been so emphatic a revival of interest in the problem of late years that I thought it might serve a useful purpose to offer a brief consideration, in classified form, of the many factors of climatic change which have been brought forward in many lands and by many writers.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

RELATIVE VALUES OF CRITERIA USED IN DRAWING THE ORDOVICIAN-SILURIAN BOUNDARY[1]

BY E. O. ULRICH[2]

(Presented in abstract before the Paleontological Society Dec. 30, 1925)

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[1] Manuscript received by the Secretary of the Society February 10, 1926.
[2] Published by permission of the Director of the U. S. Geological Survey.

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Purpose

"New times demand new measures and new men; the world advances, and in time outgrows the laws that in our fathers' day were best; and doubtless, after us, some purer scheme will be shaped out by wiser ones than we, made wiser by the steady growth of truth." (Lowell.)

Two papers in which the boundary between the Ordovician and Silurian systems is discussed were recently published in this country. The first, written by Prof. O. T. Jones, of Manchester University, England, appeared in the May-June issue of the Journal of Geology; the second, by Prof. Charles Schuchert, of Yale University, appeared in the Bulletin of the Geological Society of America, volume 36, number 2. In both papers the authors disagree with conclusions previously published by me after exhaustive study of the organic and physical evidence bearing on the question of the most natural, the most widely recognizable, and therefore the most practical stratigraphic plane at which to draw this boundary. I can not deny that Professor Jones' contribution, which discusses the question mainly from the standpoint of the European paleontologist and British practice, is an able, detailed, and perfectly orthodox presentation of the apparently opposing evidence. Really, however, we are not discussing the same problem. The difference may be expressed by saying that his aim is to fit the American faunal and stratigraphic sequence to the British standard; mine, on the contrary, is to determine which of several possible boundaries is the most natural and the most practical. In other words, my interest lies less in what has been and is being done in Europe and America than in what I think should be done. Let me

say, then, at once that my proposal is at variance with the boundary originally set between the two systems by Lapworth in 1879 and since followed by all geologists in Europe. I believed this already in 1913, but now, since going over some of the British sections with Professor Jones, I know that Lapworth's line is similarly at variance with all preceding and present practice in America.

Professor Schuchert's effort treats the subject in more generalized manner and on this account is much more easily answered, if not conclusively controverted, than is the argument presented by Professor Jones.

In my endeavor to reply to these papers I shall try to show that both authors have failed to take into account certain fundamental factors that were discussed in my papers and whose consideration was largely responsible for the trend of the conclusions therein logically attained. It will be shown that neither author even attempted to answer my leading arguments, nor brought competent evidence of either faunal or physical sorts to controvert or weaken the facts upon which the arguments were founded. Further, it will be shown that Professor Jones' reliance on generic comparisons of faunas and the commonly accepted limitation of many of the genera cited by him to one or the other of the concerned systems is not so well warranted by facts as he thinks, because the evidence as known on the two sides of the Atlantic is not strictly in accord. Finally, it must first be proved that the Richmond is represented by deposits and faunas in the typical Ordovician of Britain before we need to consider the propriety of detaching this mainly American group from the base of the naturally defined system for which we have adopted the British term Silurian.

I regret that so much of this paper must be controversial. However, I believe the reader will find most of my criticism to be constructive.

Summary of Professor Jones' Paper

In the introductory statements, comprising the first four pages of the paper, Professor Jones gives the "causes of uncertainty" in correlating the concerned British and American formations and admits the justice of Ulrich's doubt as to the actual contemporaneity of fossils listed in authoritative works then available to him as being found associated in British formations of Ordovician age. Some of the fossils thus erroneously attributed to Ordovician formations belong in fact to characteristic Llandovery species, and, as the Llandovery series is now generally accepted as making the lower division of the Silurian, they should be credited to that system and not the Ordovician.

This is followed by five pages or more devoted to a generalized descriptive statement of the sedimentary facies (pelitic, psammitic, and calcitic) of British Ordovician and Silurian rocks, the distribution and regional intergrading of the several facies in Britain, and the progress made in their faunal zoning. Important statements in the last section[3] are: (1) "the success of graptolite-zoning arises from the remarkably complete record of sedimentation which these [pellitic] rocks present and the wide distribution of these organisms and their relatively rapid change with time." (2) "The sharp changes of fossil assemblages which are observed among rocks of the calcitic facies, which make it possible to apply zonal methods, seem, however, to arise from the incompleteness of the stratigraphic record due to oft-repeated interruptions of sedimentation." I shall discuss these views at considerable length later on. In my opinion, they require modification.

The remaining nine pages of the paper are devoted to comparison of British and American Ordovician and Silurian beds and faunas. Descriptions of the formations by American writers are regarded as implying "that the greater part of the Ordovician and Silurian rocks of North America belong to the calcitic facies as defined above, and it is only in the island of Anticosti that any approach to the psammitic facies may be observed, though even there it is not typically developed.[4] It is significant that in that island the succession appears to be much more complete than in the interior areas of the continent" (page 380). He thinks also "there is little doubt that, except possibly near the base of the Ordovician, the British succession of Ordovician and Silurian rocks bears comparison in point of completeness with the succession in any other country."

On page 381 Jones expresses the opinion that "the extraordinary extent of the calcitic facies in America" probably accounts for "the abundance and variety of the bryozoan and coral fauna in America and the poverty of the British rocks in these organisms." On the other hand, he thinks "the British trilobite fauna, especially of the Ordovician, is far more varied than that of the American rocks, though fortunately there are many genera in common." Then, in carrying out comparisons between the faunas of the two countries, he relies mainly on the trilobites and brachiopods. However, these are cited by genera only. The genera are listed rather fully and separately, according as they are (1) "confined to the Ordovician," (2) those "which make their first appearance in the Silurian," and (3) those that "occur in both systems."

[3] Op. cit., p. 379.

[4] Just why the Anticosti rocks should be referred to the psammitic facies rather than the calcitic is not clear.

If no other means of arriving at the truth were available than by the simple matching of genera employed by Professor Jones in this paper, the case might, perhaps, be regarded as settled. However, even the evidence afforded by the known vertical range of the genera is not entirely in harmony on the two sides of the Atlantic; and, under the prevailing belief that the Silurian of American literature is the same as the British conception of this system, it is very much out of harmony. Besides, there are other and quite as competent means of correlating beds and geological events, and also much other evidence along lines usually avoided or ignored by paleontologists that must be considered and explained before we can accept Professor Jones' conclusions. These are, as given in the paragraph preceding the last of his paper, "that while both Upper Bala and Upper Llandovery rocks can be recognized in North America in the Richmond and Clinton formations respectively, it is doubtful whether the Lower Llandovery is represented at all, and in Britain this formation, as regards thickness of sediments, is equally important with Upper Llandovery or Wenlock. . . . Of the Albion [or Alexandria], which is tentatively correlated with that formation, a part of it, the Brassfield, is almost certainly Upper Llandovery, the other parts being of doubtful affinities, and one only, the Edgewood, suggests an overlap of Ordovician and Silurian faunas."

In a succeeding part of the present paper the paleontologic and stratigraphic evidence presented by Professor Jones is submitted to detailed critical review. I discuss especially the evidence of the graptolites.

Summary and critical Discussion of Professor Schuchert's Paper

The discussion of the subject of this paper, namely, the "Significance of Taconic orogeny," is introduced with mainly quoted statements concerning the proper interpretation of structural phenomena displayed by sections in Lehigh Gap, Pennsylvania, and at Otisville, New York. In these sections the contact between Ordovician shaly beds referred to the Martinsburg stage and massive beds of more or less conglomeratic sandstone is clearly exposed. The unconformable nature of these contacts seems undeniable, but Schuchert's remarks concerning their bearing on the "dating of the time of the Taconic orogeny" imply doubt in his mind as to the Oswego age of the conglomeratic sandstone immediately overlying the break.

In October, 1925, the present writer accompanied the Association of State Geologists on their field trips through eastern Pennsylvania. Among the many interesting localities visited were Lehigh Gap and other places showing this contact. Without exception, the geologists of

the party agreed with the opinion of preceding visitors to Lehigh Gap, that the break here is a measurably angular unconformity between beds of Silurian age above and of Ordovician age beneath. However, pending proposed more detailed investigation of the Silurian part of the section, considerable discussion and warranted diversity of opinion developed respecting the age of the first of the Silurian sandstones. The writer's opinion entertained doubts similar to those expressed by Schuchert and strongly inclined to the belief that neither the Oswego nor the Juniata are represented in the Lehigh Gap section.

The introductory part of Professor Schuchert's paper is concluded by a quotation from a letter written Doctor Ashley, Director of the Geological Survey of Pennsylvania, which, as it expresses the essentials of his attitude in the Ordovician-Silurian boundary controversy, may be repeated here:

"If your facts are correct, then the Taconic orogeny of eastern New York is continued at least to Lehigh Gap, Pennsylvania. The most interesting point in your letter, however, is the actual dating of the Taconic disturbance. We have been holding for a long time that it came between the Juniata and Tuscarora, but now you say it occurs between the Martinsburg and Bald Eagle. Accordingly, the Silurian begins with the Richmondian, but this decision is based wholly on diastrophism, a physical factor. Decidedly opposed to this conclusion are the faunal facts, the long European usage, and the statement that the orogeny in Wales came later in Ordovician time. The Richmondian faunas are modified Black River-early Trenton descendants, while the Silurian heralding does not begin until well toward the close of the Richmondian, and especially in the Gamachian."

Comments on the quoted statement probably will seem unnecessary to those who know the facts; but there are others. For the information of the latter let me say: The decision to begin the Silurian in America with the Richmondian is *not based wholly* on the physical criteria of diastrophism; nor is it opposed by the faunal facts, or by the time of the orogeny in Wales; and then what about the long American usage?

Then as to the ancestry of the Richmond fauna: So far as I know, the first public announcement of the then unexplained fact that the Richmond fauna includes modified recurrent elements of preceding Black River and Trenton faunas was made by me in 1880; and I have studied the Richmond problems ever since. In the meantime, however, we have learned that there were many quite distinct faunas of Black River and Trenton ages. They are distinct because they were developed in different seas and many of them lived a different life. But all did their best to survive recurring unfavorable circumstances and leave descendants to be incorporated in succeeding faunal aggregates. Therefore, at least to

those of us who believe in the evolution of organic beings, the recognition of descendants of earlier species in Richmond faunas is an interesting fact whose importance lies mainly in its being so much proof of the truth of our belief. Under this belief the Richmond faunas must necessarily have consisted wholly of descendants of preceding stages in the evolutionary process of marine life, and at the same time they "heralded" succeeding stages. But so also did the Cincinnatian, the Niagaran, the Devonian, the Cretaceous, and so on to the faunas of today.

But, after all, how much fact is behind Professor Schuchert's unqualified statement that the "Richmondian faunas are modified Black River-early Trenton descendants"? I would very much like to learn more about the genetic relations of the concerned faunas. Governed by the evidence in hand regarded as dependable, I would hesitate to claim that the Richmond species, whose lineal descent from Black River and early Trenton species is reasonably demonstrable, comprise more than 15 or 20 per cent of the total of 500 species known from the Richmond in the Ohio Valley alone. Now, what about the antecedents of the remaining 400 species? Most of these might be traced to Cincinnatian and late Trenton species of the same province, but not to known Black River ancestors. Besides, since descendants of many of the hardy Black River types are recognized in later Silurian faunas, why not speak of their Richmond representatives as Silurian heralds as well?

In estimating the genetic alliance of Richmond to older faunas, we should bear in mind that it makes a great deal of difference whether the compared faunal units are of the same or of distinct provinces. The result would be relatively much more negative if Richmond faunas from the Ohio Valley were compared with European faunas supposed to be of Mohawkian age.

Proceeding with the summary of Professor Schuchert's paper, the historic account of the deformation "that has come to be known as the Taconic orogeny" cites particularly the views of H. D. Rogers, James D. Dana, and Thomas H. Clark.[5] Schuchert thinks "Clark has made a clear case for the restricted import of this orogeny," but adds the conviction that eventually it will be traced much farther.

The third part of the paper discusses diastrophism and chronology.

"In the Blue Mountains the conglomerates and sands are not restricted to Juniata-Bald Eagle time. On the contrary, we see more conglomerates and much more sandstone with Arthrophycus in the younger Tuscarora and Shawangunk formations. These facts of sedimentation appear to indicate that

[5] Thomas H. Clark: A review of the evidence for the Taconic revolution. Proc. Boston Soc. Nat. Hist., vol. 36, 1921, pp. 135-163.

the Taconic diastrophism began in Trenton time, that there was mountain-making toward the close of Maysville time, and that there was more orogeny, or, at least, more elevation, at the close of the Richmondian series. . . . Mountain-making may be much localized. . . . I therefore conclude that the Taconic orogeny may or may not have the importance of dividing two series of strata into as many systems of rocks, namely, the Ordovician and Silurian."

The author then proceeds to practically demolish the commonly, but not universally, accepted belief "that the orogenies would easily delimit the periods and eras of geologic time" by citing the numerous instances in which the times of orogeny do not occur at or near the close of the major time divisions. These facts, he concludes, "should, it would seem, forever dispel the idea that diastrophism alone can be depended on to fix the boundaries of systems or even of eras." [6]

However, just before expressing dissent from the view of which he has been for years the chief proponent, he quotes from an unnamed but "good" stratigrapher, that "diastrophism affords the only means of finally attaining a reasonably accurate and systematically constructed classification." Diastrophism, he proceeds to say, "here includes all crustal movements; but even so, how are we to know their import geographically and chronologically without the help of fossils? The two sets of facts must be used together, with the further help that paleogeography and the strata can give. In other words, we must use all the evidence available in our delimitations of the various time units, and their separation must be based on the sum of all our knowledge."

To the final clause I can only add a hearty Amen: But why, may I ask, does not Schuchert prove by his writings that he acts as he speaks? Then, since I am the "good stratigrapher" whom he quotes in this connection, it seems worth while to insert here a defensive statement against implied limitations in scope of means employed by me in drawing and correlating geological boundaries. The obvious deduction from matter following the statement quoted from me is that I pay little or no attention to fossils in locating and identifying geological boundaries. The printed record of my activities during the past 48 years sufficiently negatives the implication, and my unpublished studies on fossils would more than double the printed output. I submit that I have collected more fossils with definite regard to their zonal and geographic distribution, and determined not only more of them, and of more classes, but also with greater attention to their minute details of structure and their origin and paths of migration, than any other paleontologist. And no one has

[6] The present writer agrees thoroughly with this statement, but inquires, Who ever proposed so radical and indefensible a departure from common practice?

known of this longer or better than Professor Schuchert. Moreover, in quoting from one of my papers it would have been only fair to explain the meaning of the quoted sentence by adding statements from my definition of diastrophism and diastrophic criteria, in which I definitely included "consequent organic phenomena," and therefore changes in the character and supply of faunas occasioned by crustal movements of whatever kind.[7]

It required some time to locate the particular sentence quoted by Professor Schuchert, but finally it was found on page 467 of my paper on "Correlation by displacements of the strand-line." As there given, however, the words "diastrophism" and "affords" are separated by a qualifying clause, namely, "in its broadest sense," which gives the statement a very different meaning from that implied by the incomplete form in which it was quoted. Also, a complete definition of diastrophism as conceived by me is given on the following page of the same paper (page 468).

Next, Professor Schuchert discusses the boundary itself with particular, though brief, reference to the faunal evidence. He is forced to the fossils by the asserted inadequacy of the criteria of paleogeography and sedimentation, which he says are not "in themselves decisive in fixing an unmistakable and clear boundary between the strata of the 'Ordovician system' and those of the Richmond series. . . . for, after all, paleontology is the primary basis in correlation and horizontal dating."

This hackneyed phrase about paleontology seems superfluous; for, so far as I know, no one has ever seriously questioned the indispensability of fossils in correlation. But their primacy is only in the sense that the process of correlation must be initiated by study of the fossils. They alone can give the first definite clue to the age of the concerned beds. But in many cases, especially when the desired correlation is between beds of distinct geological provinces or continents, the fossil evidence, as will be shown later, may be quite indecisive and often even misleading. We must learn to discriminate between what is and what is not competent faunal evidence and to interpret it in the light of probabilities. Two faunas that invaded the same or distinct continental basins from the same oceanic realm, but at known widely different times, might be, and in some well-known instances are, so much alike that their true age relations could never be adequately appreciated by simple matching of fossil contents. The actual difference in age would never seem so great as the stratigraphic separation of the two beds proves it to be. We have an excellent example of this condition in the Upper Stones River and

[7] See Revision Paleozoic systems, pp. 394, 535, and various passages in other works.

the Lowville faunas, which are very similar and directly superposed in Middle Tennessee, yet so widely different in age that something like 5,000 feet of Upper Chazyan deposits were laid down in east Tennessee between them.

Proceeding, Professor Schuchert quotes and agrees with the opinion of Cumings and Galloway, who "believe that the Richmond is most intimately associated with the subjacent Ordovician, both lithologically and faunally, and that it should be retained in the Ordovician system." In support of this belief he cites the preliminary faunal statistics published in 1916 by Shideler, according to which 14 per cent of the Maysville species lived on into the early part of the Richmond epoch and "not one of the Richmond species lived on into the Medina or Clinton."

Some years later Professor Shideler, who has now acquired a most extensive and accurate knowledge of Richmond faunas, read a paper before the Paleontological Society at the Ann Arbor meeting in which these statistics were almost completely repudiated. On further investigation the supposed Maysville hold-overs in the Richmond proved readily distinguishable from their ancestors. On the other hand, as will be shown later on, the Richmond contains many species that are very similar to and comparable only with Upper Medina fossils. Besides, in the first paper Professor Shideler referred only to the Brassfield, which, though resting on the Richmond in Ohio, Indiana, and Kentucky, belongs at the very top of the Medina. The typical Upper Medina fauna partly described by Hall in 1852 is as little like that of the Brassfield and Cataract as is the Richmondian. The Brassfield-Cataract fauna is closely allied to that of the Clinton. In fact, up to the present decade the "Ohio Clinton" was unhesitatingly referred to the Lower Niagaran.

Professor Schuchert closes his argument with the reminder that "the boundary between the Ordovician and the Silurian must first be adjusted on the basis of the strata and faunas in Wales, the type area for these two systems. On the basis of fossils, this boundary has never been clearly defined [a very significant admission]; yet [he proceeds to say] . . . every European stratigrapher places the correlates of our Richmond in the Ordovician." These supposed correlates and also the conclusion of the Swedish geologist Troedsson as to the position of the Richmond, quoted by Schuchert, will be referred to later when I discuss the value of graptolites in correlation. Here I will merely express my wonder as to how they managed to determine what these correlates of the Richmond in Europe are. Certainly not by specific fossil evidence!

Finally Schuchert gives his "conclusions": These are chiefly notable (1) because they speak of the faunas of Richmondian and Alexandrian

times as "markedly dissimilar" and of the break between them as of "long duration"; (2) because they introduce a new compromising suggestion, according to which a new system would be created for the reception of the Richmond and the Gamache; and (3) because they include an evidently erroneous statement of readily ascertainable fact to the effect that "the Silurian would then begin with the Upper Medina or Alexandrian series, just as our geological literature has been teaching for about seventy-five years." What I have to reply to the first of these statements will appear on subsequent pages, and the second is a solution that does not as yet interest me. However, the last statement demands immediate attention, as it implies unqualified contradiction of remarks previously published by me concerning this matter.[8] The facts seem to be as follows:

Boundary between the Champlain and Ontario Divisions of the New York System, 1842 to 1908

All four of the geologists of the first geological survey of New York—that is, Mather, whose report on the First District was issued in 1843; Emmons, who reported on the Second District in 1842; Vanuxem, whose report on the Third District also appeared in 1842, and Hall, whose report on the Fourth District was published in 1843—used the terms Champlain group or division and Ontario division for essentially corresponding subdivisions of the "New York System." The only difference in their respective arrangements of the formations they referred to these two divisions and which has any bearing on our problem is that in the reports of Emmons, Mather, and Hall the Oneida or Shawangunk conglomerate and the Gray (= Oswego) sandstone are placed in the top of the Champlain division, whereas Vanuxem refers them to the overlying Ontario division. This difference arose from the fact that Emmons, Mather, and Hall regarded not only the Oswego but also the Oneida as older than the lower red shaly sandstone (now known as the Queenston shale or Juniata sandstone), which constitutes by far the larger part of the formation to which all four of these geologists applied the name Medina sandstone. Only Vanuxem, who, by the way, was proved by subsequent investigations to have been the most dependable and clear-visioned stratigrapher of his day, referred the Oswego sandstone and the Oneida conglomerate to the Ontario division. Indeed, he not only moved these two formations upward in the scale, but he placed the Oneida *above*

[8] Ordovician-Silurian Boundary paper, p. 626; Displacements of the strand-line, p. 463; and other places.

the Medina with the definite statement that "the conglomerate forms a part of the Clinton group, the next mass in order of superposition."

Subsequently, as in Paleontology of New York, volume 2, 1852, Hall placed the Oneida conglomerate at the base of the (Upper) Silurian—that is, beneath the Queenston member of the Medina—whereas the Gray sandstone (Oswego) he says "may be regarded as terminating the Hudson River group," which is the same as placing it, as I am doing since 1914, at the top of the Lower Silurian of that date and the Ordovician of the present. Hall's classification prevailed, then, till the end of 1899, when Clarke and Schuchert's revised classification was published in their paper on the "Nomenclature of the New York series of geological formations." In this revision Vanuxem's Gray sandstone of Oswego, now generally referred to simply as the Oswego sandstone, is returned to the Ontario or Silurian side of the boundary because it "is now regarded as a part of the arenaceous sedimentation of the Medina-Oneida stage," for which they proposed the new period or group term Oswegan. Except that the Oneida was shown in 1906 by Hartnagel to belong either within the Upper Medina or at its top, as Vanuxem placed it, the boundary between the Ordovician or Champlainic and the Silurian or Ontaric has not been officially shifted by the New York Survey since 1899. Furthermore, with the exception of the Oswego sandstone, it is where Vanuxem drew it in 1842, where the official Pennsylvania surveys have always drawn it, and where the United States Geological Survey draws or at least drew it until very recently; and it is precisely where Hall recognized it in and subsequent to 1852. Also, so far as I know, no independent writer advocated a change from the long-established fixed official practice until the age equivalence of the Lower or Queenston division of the Medina and the Richmond was proved. It was only then that Grabau and other misguided paleontologists—who, being shocked by the required transferal of the Ohio Valley Richmond fauna, with its predominatingly Ordovician aspect, to the Silurian side of the line—endeavored to save the paleontological proprieties by proposing decimation of the Medina and the "Oswegan" by elimination of the offending parts. But this departure from prevailing practice was only in 1908 or 1909—that is, only 16 or 17 years ago. How, then, can Schuchert say that beginning the Silurian with the Upper Medina is "just as our geological literature has been teaching for about 75 years"?

Summary of Ulrich's preceding Paper on the Ordovician-Silurian Boundary

"In establishing the Ordovician-Silurian boundary all the available evidence, faunal and physical, both in North America and in Europe, is taken into account. In the effort to maintain the original conception of the Ordovician system as far as possible, particular care was exercised in correlating the American formations with the typical British sections. The problem is simple enough in such areas as the Ouachita basin in Arkansas, in which the character and sequence of deposits and faunas are much the same as in the British Isles. But it is not at all simple in the interior areas of the continent, where unusual stratigraphic elements are introduced and the paleontologic evidence is so different that satisfactory comparisons seem impossible.

"The more important of the varying conceptions of the Ordovician and Silurian in North America are discussed in such detail as seemed necessary to bring out their respective points of strength and weakness. The proposed 'Cincinnatic' system of Schuchert is rejected because (1) it lacks definite and practical boundaries, (2) the formations included in it are not coordinate in aggregate taxonomic value to the other Paleozoic systems, and (3) its construction is inconsistent with diastrophic principles and prevailing practice.

"The facts themselves are discussed under two heads: (1) the faunal aspects of the case, and (2) the physical aspects. Both lines of evidence seeming to lead to harmonious results, it was finally concluded that the choice of the Medina (including the Queenston) as the base of the Silurian by the older geologists is a philosophical one, with the weight of available evidence strongly in its favor. Viewed from any angle, the choice of the Juniata-Queenston in the east and its contemporary, the Richmond, in the south, west, and north, as the base of the Silurian in North America, is the only logical and wholly satisfactory solution of the problem.

"In reaching this conclusion the first important step was the decision that the highest beds referred to the Ordovician in Britain are probably older and certainly not younger than the base of the McMillan formation of the Cincinnati section and the top of the Pulaski shale in New York, and that the base of the Silurian—that is, the Lower Llandovery—is not older than late Richmond or, more probably, our Upper Medina. Obviously, then, the British sections contain no beds representing our McMillan formation and probably none corresponding to our Richmond group. Under the circumstances, we Americans must decide for ourselves how these intermediate formations are to be divided between the two systems.

"Considering the organic side of the question, which proved exceedingly intricate, it was finally shown that the greatest faunal break between the Trenton and the Niagaran, each the most typical expression of its period, occurs between the close of the Maysville and the beginning of the Richmond. More than 20 typical Silurian genera, also 4 new families, are introduced during the latter epoch. The specific break is almost complete, only some 15 or 20 representatives of persistent types out of a total of 400 Maysville species passing across the line into the Richmond.

"This greatest faunal break corresponds also to the greatest physical break.

Indeed, there is probably none of greater consequence in the whole of the Paleozoic column. Locally the contact is distinctly unconformable, and always it exhibits evidence of interrupted sedimentation and subsequent overlap, the hiatus in many instances being of great time value. The importance of the break is to be inferred also from the well-marked lithologic differences that commonly distinguish the deposits immediately following the break from those underlying it in areas where such lithologic differences are likely to obtain.

"Finally, the harmonious results achieved through the application of faunal, structural, and lithologic criteria are convincingly corroborated by paleogeographic testimony. Comparison of paleogeographic maps representing approximately 20 chronologically distinct late Ordovician and early Silurian stages of North America shows conclusively that, beginning with the Trenton, the epicontinental seas of the former period tend constantly to become smaller until, at the close of the McMillan age, the entire continent must have been emerged. This emergence closed the Ordovician, and at the same time the Eopaleozoic, sequence of events. The succeeding Richmond submergences are not only much more extensive than their late Ordovician predecessors, but they differ from them in important details. These, on the contrary, agree much better with the average aspect of Niagaran seas."

Some of the 1914 conclusions regarding the age relations of the European and American formations that lie close to the boundary are now abandoned or modified, since I have enjoyed the opportunity of studying those of Britain, Sweden, and Norway in the field and have looked more closely into the literature devoted to the description of their faunas and stratigraphic relations. Though I found nothing comparable to our Richmond faunas in Britain and the Scandinavian countries and must therefore continue to question the presence of deposits of that age in Europe, I did find abundant faunal evidence showing that the European geologists classify formations as late Ordovician that according to the American succession would not be placed lower than our Brassfield or early Clinton. To this I may add that the interrelations of the various formations and faunas that go to make up the early Paleozoic sequence of geologic events are much less fully worked out in Britain and Europe generally than in America.

Fundamental Factors not considered by Opponents

General statement

In the Revision of the Paleozoic Systems, 1911, and again, but more succinctly and partly by illustration with other examples, in the 1914 paper on the Ordovician Silurian Boundary, I discussed the criteria and principles of correlation by fossils and all other means known to and used by me. Two years later the more important of these principles were again presented, in improved form and with new illustrative examples,

in the paper on "Correlation by displacements of the strandline and the function and proper use of fossils in correlation." Of these three contributions the last is regarded as comprising probably the clearest, and therefore the best, statement of my views on the subject of stratigraphic correlation and the means of recognizing and fixing the boundaries between stratigraphic units of whatever grade. However, the importance attributed to the last paper is further accounted for by the new matter contained in it. This includes the introduction of two or more new, or at least newly stated, principles; also, the raising of "displacement of the strandline" to the rank of "dominant criterion in determining the natural divisions of geologic history" (page 468), and the definite statement that the primary and true function of fossils in correlation is "to identify horizons and not to decide how the division of geologic time into epochs and periods is to be carried out" (pages 457 and 488). "The boundaries between the deposits which we identify by these means [that is, fossil evidence] are defined only by the physical criteria of displacement of the strandline" (page 490).

Of other parts of the paper, thought to be of sufficient importance to merit special mention here, are the ten or more pages (457-467) devoted to a plea and arguments favoring and showing the need of uniformity in methods and consistency in practice; also the other pages (notably 456 and 472-488) on which the general inadequacy and probable error of results of generic "matching" of faunal contents and the percentage method of establishing the "predominance of faunal alliances" are shown by examples and reasonable deductions. Of particular importance in this connection are the sections devoted to the discussion of (1) the "causes of variation and extinction of marine species" (page 474; see also more extended discussion in Revision of Paleozoic Systems, pages 481-519); (2) the insufficiency of generic alliances among even such of the pelagic organisms as graptolites in establishing contemporaneity of deposits (page 476); and (3) the differences in composition and sequence of faunas of distinct marine provinces (page 480). For more extended discussions of these and kindred subjects the reader is referred to the Revision of Paleozoic Systems, especially pages 481-519 and 583.

One of the examples cited in showing the need of consistency in method and practice has an immediate bearing on the problem before us. In order that the time of the student may be saved, it seems desirable to quote the essentials of what I wrote about it in 1916:

"Perhaps the most troublesome are those inconsistencies which have resulted from the application of the strictly diastrophic method in one area and the purely paleontologic in another. They are distressingly troublesome, because they tend without real cause to align the advocates of the two methods

against each other in a blind and stubborn struggle in which the paleontologist fears for the very life of his principles. This is wrong, because our sole aim should be to win the truth without regard to whose method is adopted.

"A live instance of this kind is found in the Ordovician-Silurian boundary, which was drawn in New York and in the Appalachian region generally according to strictly diastrophic criteria. However, in Ohio and adjoining States to the west and south, certain highly fossiliferous beds that are now known to correspond to unfossiliferous clastic deposits in New York, which have always been classified as Silurian, were placed in the Ordovician column. There was no intent to discredit the New York classification, for that was correctly and firmly based on criteria—of the kind now termed diastrophic—whose dominance in the case of systemic boundaries was recognized then and has never been denied since; and none knew that the fossiliferous Richmond formations finger into the barren Queenston division of the Medina series. . . . Therefore, as the Richmond fossils compared much better with the Cincinnati-made conception of the typical American Ordovician fauna than they did with the succeeding Niagaran fossils, which chiefly contributed to the prevailing conception of a Silurian fauna, there was nothing else to do but to place the Richmond at the top of the Ordovician.

"But now, since we have learned many facts then unknown, and since we understand that in estimating the faunal differences then supposed to distinguish the Silurian from the Ordovician no account whatever was taken of the probably intermediate character of the fauna that must have lived *somewhere* while the great series of practically unfossiliferous Medinan deposits was being laid down in New York and Pennsylvania, what should be done? Shall we, as advocated by Grabau, Schuchert, and others, revise the New York standard and break up the practice of three-quarters of a century—a practice that was perfectly satisfactory and scientific until it ran into a prevailing, though none the less imperfect, faunal conception—or shall we, as I believe we should, hold to the New York standard and revise instead our faunal lists?"

Precisely when and what the New York State geologists did in their part of this case is more fully stated on a preceding page (289), and later on more will be said about the Medina fauna, especially that of the Upper Medina, and its relations to the Richmond faunas.

THE NEW PRINCIPLES OF 1916

The first of the new principles referred to above explains the usual discordance in age indication of marine invertebrates, on the one hand, and land animals and land plants, on the other. As this principle has no immediate bearing on the problem of the Ordovician-Silurian boundary, the reader is referred to the cited paper (pages 464-466) for its definition and application in two celebrated cases.

The second new principle, however, does have a definite bearing on our problem and therefore merits the extended attention that I propose to

give it. Though the basic idea was long before applied in my preceding practice of depending mainly on close discrimination of species in correlating formations, the desirability of giving it concrete expression as a principle was recognized only when the other principles of correlation by fossils seemed in danger of breaking down completely. It arose primarily from the need of some more reliable means of overcoming difficulties, so far as it could be done by direct matching of fossil faunas, encountered particularly in seeking to correlate formations of distinct provinces or continents. In such cases it usually proves that faunas seemingly holding nearly the same position are yet almost totally distinct, not only in species but genera. That this difference is not to be ascribed to the often great distance between the occurrences and the possibly long time required for the migration of species from one province to the other is sufficiently proved by known instances of very much greater geographic separation of faunal occurrences that are obviously of similar composition and age.

As excellent instances of such far-ranging and always easily recognizable faunas, I would mention the Ceratopea and Lecanospira faunas of Upper and Middle Canadian ages respectively. These two faunas entered Missouri from the south, passed eastwardly to the Appalachian Valley troughs, in which they have been recognized at frequent intervals from central Alabama to southwestern Quebec. Next they are found in Newfoundland, then in the northern extremity of Scotland, again in northwestern Norway, and finally in northern Greenland.

To set against these far-stretching Canadian faunas we have examples of Ordovician faunas in previously correlated beds that occur in approximately parallel bands hundreds of miles in length and only a few miles apart and yet contain only a few doubtfully identified species in common. I refer particularly to the bands of highly fossiliferous Upper Chazyan limestones and shale that lie in the eastern half of the Appalachian Valley and stretch from central Alabama to northern Virginia, on the one hand, and the limestone formations of the Stones River and Black River groups that lie in the western half of the valley. Although the laborious discovery of local lateral transgressions and consequent interfingering of these otherwise geographically separated bands has finally proved that none of the formations of either set is of the same age as one of the other set, it is not to be forgotten that only a few years ago they were assigned to the same ages and regarded as representing lithologic units or facies that varied in character according to distance from shore and sources of supply of clastic material; and such of the faunal differences as were observed were set down as merely local variations in the fauna of the

time. It should be noted, also, that simple matching of the fossils of these formations could never have succeeded in establishing their true age relations. This simple method worked very well in determining the ages of the formations in the western half of the valley, for their respective fossils were easily recognized as belonging to one or another of the Stones River or Black River faunas as developed in the standard sections of Middle Tennessee, Central Kentucky, and New York. But the case was quite different when it came to the faunas of the formations in the eastern half of the valley. These faunas comprised hundreds of species and many genera that have no near relatives in the western Ordovician faunas. However, these eastern Appalachian faunas did very strongly suggest the Ordovician faunas of Newfoundland, Britain, and Scandinavia. In short, approximate correlations with deposits in those far-distant countries were much more easily and satisfactorily effected by comparison of fossils than with those formations that lie only a few miles to the west.

Now, why are the compared faunas so radically different in the one set of cases and so harmonious in type in the other? Can it be that conditions under which migration of the concerned sublittoral faunas from one province or region to another is possible were equally favorable in both cases? Obviously not. Physical barriers of one kind or another must have prohibited further distribution of the faunas in the one case, and the removal or modification of the barriers have favored migration in the other.

Whatever the cause, these provincial differences in faunas—that while not strictly contemporaneous are yet clearly enough of the same geological period—tend to show that without other corroborating means of reaching the truth one is apt to fail in determining the precise age relations of such fossil faunas.

PERSISTENCE OF INDIGENOUS GENERIC TYPES

Our faith in the absolute efficiency of generalized comparison of fossil contents in correlating beds of two or more provinces is further weakened when we consider and contrast other pertinent facts; namely, in the long sequence of Ordovician and next younger faunas in the Baltic region, also in the similarly long sequences in Newfoundland and in the eastern side of the Appalachian Valley, and again in the equally long but otherwise very different sequences in the Mississippi and Ohio valleys, the component stages in each case are bound together by a surprisingly large number of long-ranging or genetically closely allied species. The contrast is indeed striking when we compare the relative homogeneity run-

ning through each of the mentioned sequences with the almost complete faunal discordance that distinguishes the Ordovician formational sequences in the east and west sides of the Appalachian Valley. In my opinion, the reason for this difference is that in each of the former cases the observed simulation in the composition of the successive faunal stages is because all of the stages represent invasions from the oceanic realm in which the same species and association of species lived on for long periods without suffering readily appreciable change. On the other hand, in the contrasting Appalachian instance, the faunal sequence in the west half is made up by similarly slowly modifying colonies that invaded from the Gulf of Mexico, whereas the faunal contents of the formations in the eastern half, which between themselves are also much alike, came in from the Atlantic side.

REGIONALLY VARYING DATES OF ADVENT AND EXTINCTION OF GENERA AND SPECIES

Then there is the no less disturbing but incontestable fact that the close of accessible sedimentation in continental basins, of any epoch or period, does not at the same time imply the total extinction of the species and genera found in those rocks. That they were not extinguished is obvious from the fact that the life of succeeding epochs necessarily consists wholly of more or less modified descendants of members of the older faunas. Obviously, too, the surviving species, whose descendants we recognized in formations of the succeeding period, must have existed somewhere in less changed form during the time of the intervening hiatus, the life record of which is not accessible to us. Moreover, it seems unreasonable to assume that extinction of any life unit above the grade of "local variety" occurred simultaneously in all the seas. Therefore some, and doubtless most, of the species and genera commonly regarded as characteristic of and confined to accessible deposits of the older period may be expected to have continued to live in other seas for terms of varying length.

Now, disregarding ordinary errors of observation and judgment, what reasons may we bring to explain the fact that correlations by generic matching of fossil contents are so often found to be either indefinite or positively erroneous? In my opinion, they are mainly two: first, imperfect though daily enlarging and improving knowledge regarding the complete contents of any fossil fauna, even within one and the same province; and, second, the obviously greater imperfection of our knowledge respecting the locus of origin, intermigration, and the means, paths, direction, and dates of the extension of the geographic ranges of species,

genera, and faunas from the originating oceanic realm to one or more other realms. Coupled with the latter, moreover, is the unanswerable question whether the species or genus, after such extension of its geographic range, was given the opportunity of invading the second continental province at once after its arrival or had to wait a long time till subsidence of the borderland offered the needed pathway. In view of the demonstrated fact that the vertical movements of the surface of the lithosphere were differential, it is readily conceivable that migrants of generic types that, as did so many, originated in and, for a long time, remained characteristic of the Arctic realm, may have reached the middle Atlantic or even the Gulf of Mexico long before the next submergence of the southeastern quarter of the United States afforded the means of invading the inland troughs and basins. Under present limitations we can estimate the dates of these transgressions only so far as they are indicated by discovery of their fossil remains in accessible deposits. Then it remains to determine whether the newly discovered occurrence is contemporaneous with or older or younger than the one accepted as our standard, and immediate conclusions on these accounts that are likely to stick are possible only when the compared fossils are specifically indistinguishable and therefore indicative of the contemporaneity of the two regionally separated occurrences.

Admitting this principle, as I think we must, who is to decide which of the species died and which survived, and for how long? What warrant, then, has anyone for deciding offhand, and from the obviously imperfect evidence of fossils in hand alone, the age of deposits that lie at or close to the boundary of a system and whose classification has been questioned? That certain genera, so far as known, are, for example, in Britain, confined to beds lying beneath the there none-too-well determined boundary between the Ordovician and Silurian systems, does not by itself disprove the apparent American exceptions to the British rule. To assert that such is the case is as unwarranted as would be the contrary assertion that, on the basis of the American record, the admitted presence of species of Favosites and other Niagaran genera of corals and the brachiopod genera Atrypa, Bilobites, Meristina, Stropheodonta, and Strophonella in the Bala proves the Middle Silurian age of the Bala or at least of that part of this formation which contains species of the mentioned genera. If all of the fossiliferous zones that are referred to the Bala in Britain are properly referable to that formation and actually older than the top of the Richmond in Indiana then we simply can not escape the conviction that the existence of many generic types was recorded much earlier

in Britain than in America. And the accessible record must inevitably vary in similar manner as regards the dates of their extinction.

PROBABLE MEDINAN CORRELATES IN EUROPE

Even if the shelly facies of the earlier ages of the typical Silurian were well developed in Britain, which seems not to be the case, it might still be found that the record with respect to the vertical range of some of these genera is not the same in America as in Britain or in Europe generally, where they are credited without sufficiently decisive reasons to both the Ordovician and Silurian systems. This possibility must be borne in mind so long as we do not know which of the oceanic realms could have supplied prenuntial representatives of Silurian faunas simultaneously to the Cincinnatian and Richmond seas of the Ohio Valley and the seas in Britain that Jones and others regard as contemporaneous. On the other hand, if the character of the beds were more similar and equally fossiliferous, the faunal record of the early Silurian—that is, the Richmond and Alexandria—in Anticosti and in the Ohio, Mississippi, and Appalachian valleys, might show much closer affiliations and agreement between the American and British succession than now appears from the comparison of mainly graptolitic beds in Britain and predominantly shell-bearing beds in America. Up to the present time no positive faunal evidence indicating the presence of either Richmondian or pre-Brassfield Alexandrian deposits in Britain has been discovered. Even Jones thinks the Lower Llandovery is wanting in America; and his implied correlation of the Richmond with the Upper Bala, whatever the latter may be, is based on questionable fossil evidence.

Nevertheless, I think it probable that representatives of the Medina epoch are indicated in the Kildare limestone of Ireland and the Keisley limestone of England. As was most recently shown by Miss Warburg[9] in a table showing distribution of Swedish trilobites, both of these formations are correlatable with the Upper Leptæna limestone of Sweden and the Lyckholm and Borkholm formations of Russia. Miss Warburg's work on the trilobites of the Leptæna limestone being commendable for close discrimination of species, I entertain no hesitancy in accepting these correlations as established. Besides I have for many years maintained the essential equivalence of the Lyckholm with the northern facies of the Richmond in America. Like those of the Richmond and the Alexandria, the faunas of all of these European formations include a considerable number of genera and a few species that in every case herald

[9] Elsa Warburg: The trilobites of the Leptæna limestone in Dalarne. Bull. Geol. Inst. Upsala, vol. xvii, 1925.

the more typically established Silurian faunas of the Niagaran and Wenlock series. In each case, again, the remainder of the faunas consists of modified derivatives of preceding Ordovician species that had previously invaded their respective provinces. Some of these residual genera will be mentioned on following pages, in which Professor Jones' statements concerning the age indication of British Ordovician and Silurian genera will be discussed in greater detail.

Other sources of doubt that operate particularly in the case of the Ordovician-Silurian boundary are two related facts: (1) In Wales the fullest sections of the Llandovery, some of which I enjoyed the privilege of seeing in June, 1925, under the guidance of Professor Jones, include a considerable thickness of sparingly fossiliferous beds at the base of the series. Aside from a few Lower Birkhill graptolites, which have not been found in America, the fossils consist mainly of brachiopods, among them species of Plectambonites, *Stricklandinia lens,* and *Meristina crassa,* the last of which, however, occurs also in underlying beds referred to the Bala. In America any Meristina, also anything like *Stricklandinia lens,* would be regarded as not older than Upper Medina or Clinton. The Lower Llandovery species of Plectambonites, on the contrary, are not closely allied to our Silurian species, but they reminded me, as did also those in the Bala, of some five or six undescribed species found in the Upper Chazyan and Chambersburg formations in Virginia and Tennessee. In my estimation, our Silurian species of Plectambonites are descendants of Mississippi Valley Ordovician species, which originated in southern seas and invaded America from that side. The Chazyan, Chambersburg, and lower Martinsburg species, however, had their home in the north-middle Atlantic and invaded the Appalachian Valley from the east. The Appalachian graptolites also invaded from the Atlantic side, and their zones usually alternate with those of the nonphosphatic brachiopods. These facts apparently illustrate once more the persistence of organic types within their home realms.

During the Ordovician the graptolite-bearing Atlantic currents seem to have hugged the eastern shore of Appalachia and occasionally swept through straightlike troughs which at such times separated Appalachia from the mainland to the west. In the succeeding Silurian period, however, no such straits nor pelagic faunas occurred in the Appalachian region. Except in two or three zones in western New York and southern Ontario, remains of graptolites, especially Graptoloidea, are of rare occurrence in Silurian deposits in southeastern North America. In other respects, too, though I regard the two as of essentially the same age, there seems to be no very striking resemblance between the Upper

Llandovery fauna and those of the Clinton in the Appalachian Valley south of New York. The latter remind rather more of Wenlock faunas. Among the as yet unexplained differences the apparent absence of the peculiar Clinton Ostracoda in Britain is particularly notable. Equally noteworthy is the absence of the Wenlock and Gotlandian Ostracoda in the Upper Niagaran (Lockport) deposits in America.

GRAPTOLITES AS CORRELATION GUIDES

Within the limits of a province, as, for instance, the Silurian province that stretches through Wales, Scotland, and parts of Norway and Sweden, the occurrence of certain species of graptolites in zones of limited vertical extent affords as close an approximation to actual contemporaneity of distribution in the mentioned areas as we can hope to attain. But this pleasing result is not because of the commonly accepted belief that these occurrences represent, or, rather, cover, the life-span of the particular characteristic species of graptolite, but because they mark the times of particular invasions of the province. In other words, they mark the times when circumstances were favorable to the invasion of the province by swarms of the concerned species. Doubtless indistinguishable earlier and later stages of these specific entities existed elsewhere without meeting conditions favoring their entrance into the British graptolite province. For correlation purposes, therefore, these graptolites have precisely the same significance and value that I have ascribed to the invasions of late Ordovician seas in southeastern North America by the shell *Orthorhyncula linneyi*.[10] In both cases the zones in which these guide fossils occur are real datum planes within their respective provinces. However, when found in other provinces and other continents the indexical values of the species may not be precisely the same. Indeed, they may be very different.

High indexical value in detailed correlation being properly attributable to occurrences of species of graptolites only when these occurrences represent dates of particular brief invasions and only so far as the area of the province is determinable, it seems extrahazardous to suggest or claim that genera known to be represented at or well up toward the top of the Ordovician never and nowhere transgressed the boundary between it and the succeeding Silurian period. Knowing that even in Britain the genera, and in a few instances species, and even varieties, of Climacograptus, Orthograptus, Glyptograptus, Mesograptus, and Plegmatograptus ranged across the line, why deny this possibility to other late Ordovician graptolites? Granting, too, that in Britain Dicellograptus

[10] Revision Paleozoic systems, 1911, p. 514.

ranged to but not across the line, why may not a descendant of the last of the British species of this genus have lingered on, say, in America, just long enough to be recorded in the lower part of the Richmond stage of the Silurian in Oklahoma? These possibilities must be conceded at least until discovery in northwestern Europe of positively identified elements of the typical fauna of the Richmond has proved the latter to be of the same age as the Upper Hartfell of Britain and not, as I believe, younger.

The improbability of the Richmond being either in part or whole equivalent to the Upper Hartfell seems sufficiently indicated in my discussion (Ordovician-Silurian Boundary paper, 1914, pages 320-322) of the graptolite zones in the Ouachita geosyncline of Arkansas. In this paper I reported that the three graptolites—*Dicellograptus complanatus ornatus, Climacograptus ulrichi,* and *Orthograptus crassitestus*—found in the basal 10 feet of the early Richmond Sylvan shale in Oklahoma seem indistinguishable from species found with many other graptolites in the upper 50 feet of the Polk Creek shale in Arkansas. The latter formation comprises the highest of the Ordovician deposits in the Ouachita geosyncline and is synchronized with the Upper Hartfell on the basis of general similarity of their graptolite faunas. This correlation is further suggested by the unquestionably Silurian (Middle Birkhill) graptolites of the Blaylock sandstone, which rests unconformably on the Polk Creek. Considering the question from all sides, I see no reason to modify my previous view that the upper Polk Creek occurrence of *Dicellograptus complanatus ornatus,* rather than the subsequent appearance of the species in the Sylvan shale, corresponds to the *Dicellograptus anceps* zone, in which it occurs in Britain. In thinking of this, it may help some to remember that the species of Dicellograptus are not very notable for shortness of vertical range. Indeed, the ranges of *D. forchhammeri* and *D. moffatensis* seem uncommonly long, that of the latter, as given in Elles and Wood's monograph, being greater than the vertical range of any Ordovician species of corals, bryozoans, brachiopods, mollusks, or crustaceans known to me.

Careful analysis of Elles and Wood's table showing the zonal distribution of the graptolites in British deposits brings out, when checked with the ranges of the same and other classes of fossils in America, so many contradictions of the prevailing belief concerning the sensitiveness of the measure of geologic time afforded by the graptolites that I must henceforth decline to credit them with greater advantages than may be gained by equally intensive study of the other classes. Indeed, considering the difficulties in precise determination of the species and varieties inter-

posed by their usually unfavorable preservation, I doubt very much if the fossilized remains of graptolites are, as a rule, even nearly so well adapted to fill the functions of exact correlation criteria as are the trilobites, crinoids, bryozoans, or the articulate brachiopods.

I have always experienced great difficulty in determining the actual age relations of the graptolite zones to those of the limestone, shale, and sandstone formations which contain few or no graptolites, but are no less clearly and definitely punctuated by zones which are recognized and identified from place to place by characteristic remains of shell-bearing animals. In America we have only one important graptolite formation whose position with respect to formations of the limestone facies is definitely known. This is the Athens shale, which contains a good representation of the Normanskill or Upper Glenkiln and Lower Hartfell graptolite faunas. But the determination of the position of the Athens in the general time scale is due mainly to the fact that the Athens is limited both above and below by limestone formations containing large shelly faunas. Concerning the age of the Deepkill or Levis graptolite series we know only that their greater middle part is of Upper Canadian age, but whether their tops reach into the base of the succeeding system or their bases down into the Middle Canadian remains to be learned. Then there are at least 2,500 feet of limestones before we come to the next lower graptolite zone (Staurograptus in base of Canadian), and beneath this more than 6,000 to the Upper Cambrian *Dendrograptus halli* zone. Upward from the Normanskill zone one passes through 5,000 feet of beds before meeting graptolite faunas that suggest those of the topmost zone of the Lower Hartfell of Britain. After that approximately 2,000 feet of beds were laid down before we come to the lowest of the Richmond graptolites. Considering the great gaps between the Eopaleozoic graptolite zones, are we warranted in endowing the graptolites with unusual sensitiveness as means of measuring geologic time?

CAUSES OF SUCCESS OF GRAPTOLITE ZONING

In the preceding résumé of Professor Jones' paper I quoted him as attributing the success of graptolite zoning in correlation to the remarkably complete record of sedimentation which the pelitic rocks present, the wide distribution of these organisms, and their relatively rapid change with time. Though granting the exceedingly high value of the graptolites in correlation, especially intercontinental correlation, it yet seems to me success of graptolite zoning arises rather more from other causes than the first and third given by Jones. It arises primarily from their floating pelagic habit, which permitted rapidity of transportation

by currents and resulted in uncommonly wide distribution. I doubt that they changed more rapidly in appreciable and readily distinguishable degree than did other classes of organisms of equally complex structure. I doubt, also, that the pelitic facies of rocks, as developed in any one locality, ever includes either as complete a record of sedimentation or even one so nearly full as is commonly preserved in examples of the calcitic facies. The modification of the species to specifically distinguishable stages usually required long periods of time, and, as I have repeatedly written,[11] the major part of these modifications was accomplished in the permanent oceanic breeding grounds and not in the only periodically submerged continental troughs and basins. The ancient marine life in the latter must, therefore, be conceived as consisting mainly of adventurous or involuntary colonists that invaded the continental seas when conditions were favorable. Moreover, the duration of the stay of these colonists in parts or the whole of their new habitat depended on the continuance of conditions favoring their existence. All of this, then, points to the conclusion that it is only an occasional segment of the endless evolutional film that Nature has preserved in the available parts of the sedimentary record for the information and guidance of the stratigraphic paleontologist. At that we have trouble enough with the "varieties," "mutations," and "individual variations" that have been carelessly slipped into the record. But if, on the contrary, the accessible sediments of any one or all of the geological periods included anything even approaching a complete record of the slowly progressing and practically imperceptible evolutionary changes in the marine life of past geological ages, what possible success could have rewarded the efforts of the paleontologist who tried to divide the rocks into faunal zones? I take it, then, that the success achieved in graptolite zoning is due rather to the imperfection than the perfection of the record of sedimentation in the graptolitic mud-rocks. The same conclusion is reached after comparison of the sedimentary records of the graptolitic shales on the one hand and the non-graptolitic limestone deposits on the other.

That the beds of the graptolite-bearing pelitic facies usually represent a less continuous depositional record of the time covered by the entire series to which they belong than do calcitic facies in general, is clearly indicated by facts or views that are generally accepted, at least in America. Thus, graptolitic formations, as, for instance, our Levis and Athens shales, which together correspond approximately to the British Arenig, Glenkiln, and Lower Hartfell formations, attain notably inferior thick-

[11] Revision of the Paleozoic systems, pp. 495-505; Ordovician-Silurian Boundary, p. 632; Correlation by displacements of the strandline, etc., p. 474.

nesses than do their calcareous equivalents in near-by localities. The difference in this respect is particularly notable when we compare sections of the Athens in which the graptolitic beds are many and occur at frequent intervals through a large part of the formation with others in which the profusely graptolitic zones are few and generally confined to the basal fourth or less and considerable parts of the remainder of the formation consist largely or wholly of limestone. In the former facies the total thickness of the Athens rarely exceeds 1,000 feet, whereas in the relatively calcitic latter facies it may exceed 3,000 feet. Similarly, in the case of the older Levis and Deep Kill graptolite facies, which is approximately 600 feet thick at both places, the difference as compared with the probably equivalent deposits of the calcitic facies is no less notable. The difference in volume of deposits is still great, even when we assign the whole of the Levis and Deep Kill formations only to the Upper Canadian; and it is much greater when we permit their bases to range back into Middle Canadian time and their tops into earliest Ordovician (Ulrich, not Lapworth). The truth of this statement is apparent when we remember that the thickness of the calcitic facies of the Upper Canadian alone exceeds 800 feet in the Champlain Valley, 2,000 feet in central Pennsylvania, and at least 2,000 feet in central Oklahoma. The importance of these facts in controverting the questioned statements is further emphasized by the generally accepted view that under average conditions the rate per foot at which shaly deposits are laid down is greater than that for limestones. Following these considerations, the only logical conclusion is that the progress of pelitic sedimentation must have been subject to frequent periods of retardation if not complete prohibition.

Some of the breaks in the sequence of British graptolite zones are clearly indicated in Elles and Wood's tables showing the vertical distribution of the species. As strong as any is the one between the *Pleurograptus linearis* zone of the Lower Hartfell and the base of the Upper Hartfell. This had already been noted by Troedsson, who speaks of it as an "unobserved discordance." Another strong break is between the *Dicellograptus anceps* zone of the Upper Hartfell and the base of the Birkhill, the latter of which corresponds approximately to the base of the Llandovery. This hiatus probably covers the time of the Medinan in America, including, of course, the Richmond; and it is suggested also that the Keisley and its correlates in Ireland, Norway, and Sweden will fall into the same gap.

Stratigraphic breaks of this order should be marked by unmistakable physical phenomena, but I find no mention of them in the descriptions

of the British graptolitic formations. Judging from the American record, I would expect to find also at least one and probably two physically indicated breaks between zones referred to the Glenkiln formation. Beginning, as that formation does, with the zone of *Didymograptus murchisoni*, which seems not far above the top of the Canadian system in this country, and ending with the zone of *Climacograptus peltifer*, which occurs well up in the Normanskill shale of Upper Chazyan age, there ought to be some hiatuses to help cover the great time indicated in American sections between the base and top of the Glenkiln.

The stratigraphic positions of *Amphigraptus divergens* and *Pleurograptus linearis* in the two continents may help some in determining the time value of the break between the Lower and Upper Hartfell. This break must be of considerable significance, because in Britain it marks the extinction of all but one of the 35 species found in the three Lower Hartfell zones. In Britain both of the mentioned species are confined to the top zone of the Lower Hartfell. In America, however, their occurrences are widely separated, the Pleurograptus being found in the Upper Utica, whereas the Amphigraptus has been found only in Normanskill beds of Chazyan age. In America, therefore, these two graptolites, which are found associated in the same zone in Britain, are separated by something like 5,000 feet of limestone and calcareous shale. However, assuming that the occurrence of the Pleurograptus is approximately synchronous on the two sides of the Atlantic, then we still have some 1,500 feet of Eden sediments and as much as may be needed of over 500 feet of Lower Maysville beds before we come to the Upper Maysville (McMillan formation and Oswego sandstone), which I am quite ready to accept as the American equivalent of the Upper Hartfell.

If we find it difficult to correlate by species of graptolites across the Atlantic, how much more indefinite and inconclusive must be correlation by genera!

However this question of relative merit may be decided, the result is not of immediate importance, because the fields in which their respective functions operate are usually distinct, and it is only when they overlap or alternate that we need to judge between them. The true and distinctive value of the graptolites is twofold: it lies (1) in providing the basis for a standard sequence of zones by which thick series of beds, previously of almost undecipherable relations, are now classified in reasonably satisfactory manner; and (2) in the excellent service rendered by them in intercontinental correlation. The fact that their remains usually occur in abundance and variety enabling the investigator to check his conclusions by multiple comparisons should perhaps be added

as a third quality of value. But we have little cause to lament the paucity or usual absence of their remains in the more extensive interior outcrops, for in these the function of the graptolites is performed at least as well by the other classes of fossils.

TROEDSSON'S PROBABLY ERRONEOUS CORRELATION OF THE RICHMOND WITH THE GRAPTOLITIC POLK CREEK AND UPPER HARTFELL SHALES

Among several instances of probable error in correlating formations vitally concerned in the present problem, I may mention the graptolite evidence on which Troedsson[12] bases his conclusion that the Polk Creek shale of Arkansas is to be correlated with the Richmond, both of these with the Upper Hartfell of Britain, and all three with the Brachiopodskiffern (Leptæna limestone) of Sweden and the Lyckholm-Borkholm of Russia. I find it far from convincing, particularly as regards its efficiency in proving the asserted Richmond age of the Polk Creek shale. In my preceding (1914) paper on the Ordovician-Silurian boundary I referred the Polk Creek shale to the age of the Upper Hartfell, which is generally accepted as closing the Ordovician record in Britain, and proved to my own satisfaction that both of these abundantly graptolitic formations are older than the graptolite zones in the lower part of the Richmond.

On page 302 I gave reasons for doubting the general European assumption that Dicellograptus, which ranges from the Upper Canadian *Didymograptus bifidus* zone to the last of the Ordovician zones in Britain and of which most of the species range across two to five or six of the graptolite zones, could have become extinct everywhere and simultaneously at the close of Upper Hartfell deposition in Britain. Another genus, or, rather, species, that is important in this connection is *Climacograptus scalaris*. Like Dicellograptus, this genus, as recorded in Britain, also comprises more long-ranging than short-ranging species, and this is true especially of the late Ordovician and Silurian species. Among the latter is *C. scalaris*, the typical form of which, as given by Elles and Wood, is confined to the Upper Birkhill zones 19, 20, and 21. However, they recognize some very closely related older varieties of the species which extend upward from the Upper Hartfell across the systemic boundary into the lower two or all three of the Lower Birkhill zones. Indeed, the variety *normalis* ranges even into the lower part of the Upper Birkhill. Now, assuming that it is really the variety *normalis* that occurs in what Troedsson calls the youngest of the Ordovician in Sweden, how can he prove that it represents the first British occurrence of this variety (in

[12] Gustav Troedsson: Vastergotlands Yngsta Ordovician, 1921, particularly p. 18.

the zone of *D. anceps*) and not one of the subsequent Birkhill occurrences? No doubt his opinion in this matter was induced mainly by the "dominant Ordovician" aspect of the associated fossils. However, among the latter there are many that must appear decidedly post-Ordovician to American stratigraphers. In fact, with one or two exceptions, namely, *Remopleurides radians* and *Plectambonites sericeus*, every one of the 28 species listed by Troedsson[13] would pass in America without seeming to merit critical comment as to its Silurian age. Another, and perhaps better, reason may have been the reported occurrence of *Diplograptus* (or *Cephalograptus*) *acuminatus*, a characteristic Lower Birkhill fossil in Britain, in shales overlying the beds with *C. scalaris normalis;* but it seems Troedsson failed in his effort to verify the supposed stratigraphic relations of the two species. Further doubt as to the presence of the Lower Birkhill representative of *D. acuminatus*, which is usually associated with *C. scalaris normalis* in Britain, is the fact that in Skane the Rastrites zone immediately succeeds the zones with Climacograptus. Moreover, in Britain the nine species of Rastrites there distinguished, also the other more typical species of Cephalograptus, are all confined to Upper Birkhill zones. Therefore, even granting that Tullberg found a graptolite that he regarded as identical with *D. acuminatus* in the lower part of the Rastrites zone in Skane, it may still prove either that it represents a younger stage of that species than the one by which it is known in Britain or one of the Upper Birkhill species of Cephalograptus.

The paleontologic evidence on which I based my correlation of the Polk Creek shale with the Hartfell of Britain in 1914 stands as well today as then. None of my critics has paid any attention to either the facts or the argument, except to pick out the admitted fact that among the numerous Polk Creek graptolites are three that are represented by very close or indistinguishable descendants in the basal part of the Sylvan shale. This shale overlies a thin limestone that agrees closely in its abundant fauna and lithic characters with the Fernvale limestone (basal Richmond) in Missouri and northwestern Arkansas. In studying the problem, it is important to remember that the Sylvan shale belongs in the Arbuckle part of the interior province, and that it contains a perhaps contemporary variant of the Maquoketa shale fauna of Iowa, Missouri, and northern Arkansas which in those States also immediately supersedes the Fernvale. On the contrary, then, is the fact that the Polk Creek shale is a member of the Ouachita graptolitic shale facies of the Atlantic province; also, that *Dicellograptus complanatus* ranges through its entire thickness of 460 feet, but that the variety *ornatus*, which in

[13] Op. cit., p. 12.

Britain is confined to the uppermost, *D. anceps,* zone of the Hartfell, occurs with normal *D. complanatus* in the upper 50 feet of the Polk Creek shale. Again, that the Polk Creek is locally succeeded by 1,500 feet of Blaylock sandstone, which at some undetermined but considerable height above its base contains an unquestionable Middle Birkhill graptolite fauna; also, that, with the exception of similar forms of *Dicellograptus complanatus, Diplograptus crassitestus,* and *Climacograptus ulrichi,* the two provinces, that of the Polk Creek shale and that of the Sylvan, have almost nothing in common, either as regards the lithology of their respective formations or the composition and originating sources of their faunas. Finally, in view of the further fact that the rocks of these two provinces are separated at one place by a distance of less than 15 miles, it seems very improbable that any two formations of their respective sequences are strictly of the same age. The only exception that at present seems more than merely possible is that the Blaylock sandstone, 1,500 feet in thickness, represents the whole of the Medinan, in which case its lower part would correspond in age to the Richmond.

The presence of the mentioned three species of graptolites in the Sylvan shale was and is still explained as an instance of briefly surviving residuals of preceding late Ordovician faunas. I see no reason for attaching greater significance to this survival than pertains to the known continuance of other species of Upper and even Lower Hartfell graptolites into Lower Birkhill zones in Britain. If the latter could manage to prolong their existence there, why may not others have succeeded as well elsewhere? In fact, if the Richmond is really, as I believe, entirely older than the base of the Birkhill and the base of the Llandovery, then the persistence of the British examples of graptolites that survived the break between the Ordovician and Silurian systems is far more extraordinary, not to say "shocking," than the Sylvan survivors which lived only for a relatively short time after the beginning of the Richmond.

Having thus shown why I can not subscribe to Troedsson's opinion regarding the equivalence of the Richmond and the Hartfell, I feel impelled to enter a protest also to his unqualified correlation of the *Dalmanites mucronatus* beds with the *Dicellograptus anceps* zone of the Hartfell. So far as I can see, he neither presents a shred of competent faunal evidence in support of his view nor does there appear to be anything to suggest equivalence of these beds save the fact that each in its own country immediately underlies beds that on account of the presence of monograptids are regarded as introducing the Silurian. The *"Dalmanites ledet"* most probably correlates with the Upper Leptæna limestone of Dalarne and the Keisley limestone of England, and if these

formations have equivalents in the Medinan (including, as this term should, the Richmond), then they must be in the upper part of this American series and not in the Richmond part.

CORRELATION BY IDENTIFICATION OF MINUTELY DISCRIMINATED FOSSILS

Impeaching facts and considerations like the foregoing, which were already well understood ten years ago and clearly set forth in the paper on "Correlation by displacements of the strand-line," established the need of some more definite and less questionable means of correlating geologic events by fossil evidence than those generally employed before. To meet this need and to save and justify the reputation of fossil evidence in correlation, the second new principle was formulated and presented in the cited paper. As then defined, the principle rests on and demands the closest possible discrimination of the fossils.

"The only kind of fossil evidence that has a definite and unimpeachable correlation value is that afforded by the identification of relatively trivial biological differentiations. In the very nature of things *these*, be they called varieties or mutations, *must* be trustworthy indices of contemporaneity. If the basic principles of the idea is apparent, then the reader will see at once also the truth of the following qualifying or at least kindred principle, namely, *the inherent correlation value of a fossil species is in proportion to its complexity of structure, being greatest when the complexity is in parts which are structurally unessential.*

"On the contrary, simply constructed organisms, with few characters that might be preserved in the fossil state—as, for instance, a shell with rounded, low conical form and smooth or but simply marked surface—these are of little value, because such types usually persisted through long ages, and their numerous successive occurrences are often so much alike that the human perceptions are incapable of distinguishing them.

"The differentiations regarded as particularly valuable are such as pertain to the surface marking or ornament of shells of mollusks or brachiopods; granulation and peculiarities of venation of the test of trilobites and ostracods, or, better still, nodes in some cases and pits in others on the middle of the head and on free cheeks; or spines on the head, tail, and pleura which occur in endless variety of number, length, and arrangement; in the case of the conodonts and annelid jaws, which often are found in beds otherwise nearly barren, excellent criteria of this kind are offered by peculiarities in the number, arrangement, length, and thickness of the denticles. Though any of these features may be repeated more or less precisely in other species of the same genus as well as in other genera of the same class, combinations of two or more minor peculiarities are commonly notable by which the several occurrences may be distinguished, and *these combinations are never exactly reproduced.*

"Extravagance in development of any feature could not have lasted long; hence species so distinguished are reliable horizon markers. Even the Ostracoda, referring particularly to the more or less complexly marked Beyrichiidæ

and Cytheridæ, are of great value in identifying horizons. Valves and entire carapaces of these small crustacea often are exceedingly abundant, widely ranging, and commonly better preserved than are the remains of other classes of fossils. I found them most useful and reliable in correlating the Silurian and early to Middle Devonian formations in the Appalachian region.

"Composite types like the Bryozoa, which have many individual and colonial characters, are especially useful, because biologically unimportant differentiations may yet, and commonly do, produce positively recognizable combinations. The Bryozoa have been of the greatest help in correlating Ordovician and Silurian horizons; and now the detailed studies of Canu and Bassler are proving them to be equally valuable in establishing the time relations of Tertiary deposits in the southern Coastal Plain of the United States.

"By the recognition of such minute structural differentiations we actually identify geological horizons, for it seems practically impossible that the same combination of minor and major biological characters can have existed either very long or more than once. In my opinion, therefore, the occurrence of a single finely drawn variety in two or more widely separated places—be they in the same province or not—is a more trustworthy indication of the contemporaneity of the beds containing it than would be any quantity of the indefinite testimony afforded by generic alliances."

I am glad to report that practically all the active paleontologists of today, and perhaps even more generally in Europe than in America, are studying their material with more discriminating perceptions than formerly, when it was thought praiseworthy rather than blameworthy to stick an old name on a new thing. It pleased me particularly to observe Professor Jones' guarded though well warranted enthusiasm in developing the method of close discrimination in his studies on the brachiopods of the Ordovician and Silurian formations in Wales. The results of these investigations, though as yet largely confined to the species of Plectambonites, are helpful in perfecting the record previously outlined through zonal collecting and study of the graptolites.

The practical separation and recognition of species of this widely distributed and interminably diversified genus of brachiopods had previously been regarded as an impossible task by both European and American paleontologists; and indeed it does require much patient application. But, as I proved to my satisfaction long ago, it is not only feasible, but most promising of desirable results. Pending the arrival of opportunities to undertake and complete a comprehensive study of Plectambonites and allied genera—opportunities that I am now certain will be denied me—I endeavored to identify the already numerous described species and distinguished many previously unrecognized species or varieties that were or promised to be useful in my stratigraphic work.

Though rather generally despised and neglected by stratigraphers because of their reputation as "long ranging fossils," my own experience

with the species of Plectambonites gave me no reason to doubt that when properly treated their value as index fossils is quite as high as that of other more popular kinds. If, then, we consider the many thousands of carefully collected specimens already available in American museums for study and the ease of procuring further—in fact, unlimited—quantities of new material, this and other genera of brachiopods may be recommended as an inviting and hitherto very slightly worked field for some young paleontologist.

All the matters discussed on the preceding 20 pages I regard as fundamental factors in determining the time relations of formations by the evidence of fossils. It seems, therefore, that they should be taken into account before we finally decide where boundaries between formations and systems may be most naturally and consistently drawn. If the validity of these premises is admitted, then I may conscientiously charge those who have chosen to oppose my views on the question of where the boundary between the Ordovician and Silurian systems should be drawn in America with having neglected most important means of weighing their evidence and claim that they have failed to establish their conclusions. On the other hand, not a single essential fact presented by my opponents was unknown and remained unconsidered by me before reaching my contrary views. Moreover, the collections of fossils from Ordovician and Silurian formations in American museums, especially the United States National Museum, include so much important, though as yet unpublished, information concerning the character and distribution of the life of these periods that I may, perhaps, justly regard myself as having had as full opportunity to consider the faunal aspects of the case as have those who hold different views.

The only kind of fossil evidence that I can admit as worthy of credence in opposition to my contention is the proved occurrence of fossils, identical in major and minor structural features with typical upper Richmond species, in British deposits whose position beneath the base of the Lower Llandovery is positively demonstrable. When such evidence is submitted, then the question of the dominance of the physical criteria of displacement of the strandline over fossil evidence in fixing the boundaries between stratigraphic units of whatever grade will be squarely before us; also the question whether consistency in methods of classifying formations shall or shall not prevail, and precedent and priority rule rather than natural relations, accuracy, and final convenience; or, to express the last idea in other words, whether methods and practices that seemed good in the days when the term "shifting" was applied to faunas rather than seas and their shores, and when the surface of the continents

was believed to have been relatively stable and not, as we now believe, subjected to frequent and varied warping and tilting, shall continue to operate without modification in these days of changed conceptions. Then, too, we shall have to decide as to the advisability of cutting off so much of what every American geologist assigns to the Silurian as may be required to meet the British contention that the system be limited below at a plane corresponding to the base of the Llandovery in Wales, or whether we shall recognize some lower systemic boundary that is more conveniently and more naturally indicated in the American stratigraphic succession.

Critical Comments on Professor Jones' Paper

General Statement

On page 380 of his paper, Professor Jones remarks, very truly, that certain statements by me "regarding the relative completeness of the record furnished by the Ordovician and Silurian rocks of Britain and America follow from the fact that his experience . . . has been derived mainly from the study of the American lithological and faunal succession." However, since I have seen some of the best of the British outcrops of these rocks, it seems to me the statements complained of by the British authority err, if at all, in being too conservative. Further, I doubt if I can quite agree with his following statement that in Anticosti "island the succession appears to be much more complete than in the interior areas of the continent." If he refers only to the number of species found in the early Silurian formations, I might, perhaps, have to concede slight advantages to the middle and upper parts of the Anticosti section. The Richmond part (English Head and Charleton), with only 182 species, falls far short of the total of over 500 species known to occur in the Richmond of the Cincinnati dome; nor does the Clinton part (Gun River, Jupiter River, and Chicotte?) seem to have produced more species than we know from the Clinton deposits in New York and the Appalachian Valley. Even the middle part, meaning by that the Ellis Bay and Becsie River formations, and providing I am right in referring these to the age of the Upper Medinan or Alexandria group, must have a larger fauna than there is any published reason[14] for believing to outnumber the 200 species represented in my collections from the formations of this epoch in Missouri and Illinois, or the aggregate from formations of similar age in the Appalachian Valley, western New York, and Ontario. However, if Professor Jones' statement refers to relative

[14] Twenhofel's lists cite 164 species from the Ellis Bay and Becsie formations, with 144 species in the former and 39 species in the latter and 19 common to both.

thickness of deposits, whether fossiliferous or not, there is still some reason for questioning the accuracy of the statement. For the facts in the case I refer the reader to the discussion of the stratigraphy of the Silurian system in the Appalachian Valley recently published by Swartz and Ulrich and Bassler.[15]

In comparing the successive early Silurian faunas in Anticosti, the middle Appalachian Valley, and the Ohio and Mississippi valleys, it will be observed that the Alexandrian faunas in each are not wholly different from the Richmond faunas beneath them. Many of the Ordovician genera and a few species of mainly simply constructed types pass on through the Richmond into the Upper Medinan and Niagaran formations. Following the Richmond, they rapidly decrease in number, so that the Brassfield and Cataract faunas are predominantly of typical American Middle Silurian aspect. But this can not be said of the faunas of the middle and lower divisions of the Alexandrian or Upper Medinan, for in these the Richmondian and, to that extent, the Ordovician aspect is still dominant (see pages 343-346).

Another matter that will be observed is that the Richmond, Alexandria, and Clinton faunas in each of the provinces differ more or less decidedly from those of similar ages in the other provinces; also, that the species or near relatives which bind the successive faunal stages of each province together are not the same forms that serve this purpose in the other provinces, but mostly different genera and species in each. In other words, most of the survivors in each case are unknown in the other American provinces and therefore characteristic of their own.

On page 381 Professor Jones mentions the "striking difference in the general character of the faunas on the two sides of the Atlantic, namely, the abundance and variety of the bryozoan and coral fauna in America and the poverty of the British rocks in these organisms." Then he concludes "there is little doubt that conditions were more favorable in America for the existence of these organisms." Presumably he refers to ecological conditions. If so, then I must question the opinion, because I see no reason for believing that differences in living conditions were responsible in this case. On the contrary, the poverty of the British rocks in these organisms, especially the Bryozoa, was most probably occasioned by physical barriers that prevented their migration into the Ordovician and early Silurian seas of Britain.

The corals, apparently, originated in the Atlantic north of Florida and soon achieved a slender foothold to the south in the realm that supplied most of the Paleozoic faunas that invaded America from the Gulf

[15] Maryland Geological Survey, Silurian volume, 1923, pp. 19-391.

of Mexico. However, the southern colonies, which—disregarding Tetradium, which seems a very doubtful coral—comprised only a few species of Columnaria and Petraia, apparently died out before the close of the Richmond and left no recognizable descendants. But with the beginning of the Richmond a strong northward migration and accelerated evolution of the corals set in. The Arctic realm thereafter to the close of the Niagaran supplied the corals of the Silurian faunas that invaded northwestern Europe and America from the north. After the Richmond, paths were opened permitting the northern corals to recover their range in the southern realm; and it was this realm that supplied the sparse Alexandrian and the succeeding much larger Niagaran and Onondaga coral faunas that are so wonderfully developed in the vicinity of Louisville, Kentucky. But for some reason neither of these realms could supply any considerable coral fauna to either the late Ordovician or early Silurian seas in Britain or the Appalachian Valley region.

The Bryozoa also seem to have originated in the Atlantic and about the same time as the corals. Like them again they came into the continental basins mainly from two centers of distribution—the Arctic and the Gulf of Mexico. However, they developed somewhat differently in these two realms and in both attained much greater diversity during the Ordovician than the corals. As a rule, the northern forms are specifically and to a considerable extent also generically distinct from the southern; and the relations between the northern bryozoan faunas and those of the Atlantic faunas in the eastern belts of the Appalachian Valley are notably greater than between either of these and those of the faunas that invaded from the south. We know practically nothing of what happened to the northern bryozoan faunas after the close of the Richmond. Much more is known concerning the further development of the southern types. During the Richmond transition from the Ordovician to the Silurian the main change in the composition of the fauna was by gradual extinction of previously very prominent genera and introduction of generic types that became prominent in subsequent Paleozoic faunas. But—with the exception of the exceedingly simple Cyclostomata, like Stomatopora, which from the first of their Ordovician representatives on to the living species are almost indistinguishable specifically—none of the Richmond Bryozoa is precisely like its Ordovician ancestors. Only a few of these Bryozoa got into Britain, and those of the "upper Bala" and the Llandovery that I have seen are of genera or sections of genera that occur in America no lower than the Richmond or the Upper Medinan. That so few arrived there evidently requires no other explanation than that the

laws regulating migration eastward from America were then unfavorable to the Bryozoa and corals.

Professor Jones then proceeds to say that "the British trilobite fauna, especially of the Ordovician, is far more varied than that of the American rocks"—a statement that would scarcely have been warranted ten years ago, when Bassler's Bibliographic Index listed no less than 46 genera of post-Arenig Ordovician genera of trilobites in American formations. Raymond has since proposed other genera from this system, and if we count ten or more new genera of which the descriptions remain to be published, the total number of Chazyan, Mohawkian, and Cincinnatian genera of trilobites known today will exceed 60 and the species 500.

STRATIGRAPHIC RANGES OF BRACHIOPOD AND TRILOBITE GENERA

In the following pages we find incomplete lists of British genera of brachiopods and trilobites arranged according to their supposed vertical range: (1) those genera that "appear to be confined to the Ordovician," of which 33 brachiopods and 30 trilobites are mentioned; (2) those "which make their first appearance in the Silurian," 28 of such brachiopods and 3 of trilobites being mentioned; and (3) those genera "which occur in both systems, though usually represented by different species," the lists of these comprising 32 of brachiopods and 16 of trilobites. I object on principle to correlations based solely on generic similarity of the compared faunas, but there are other features of these lists that afford legitimate grounds for critical comment. Of course, we assume for the present that the generic identifications are the same in Britain and America. Doubt on this account is particularly suggested among the brachiopods. The main purpose of the following comments is to show that the accredited vertical ranges of the genera is often different on the two sides of the Atlantic and also in different provinces of the American continent.

Among the genera of brachiopods listed as confined in Britain to the Ordovician we come first to *Acrothele* and *Acrotreta?*. Both of these genera are widely distributed in our Cambrian formations, and the first has been recognized only in rocks of that age. The second, however, does appear to be represented by congeneric species in the Ordovician rocks of the Appalachian Valley to the top of the Blount group (Upper Chazyan). Then there is Cliftonia, which begins with us in the Chazyan fauna of Atlantic origin and then comes in from the same side on three subsequent occasions, namely, at the beginning of the Trenton, again at the close of the Trenton, and finally near the beginning of the Rich-

mond; but this type of shell is not seen in the faunas that invaded from the south until well up in the Silurian. The genotype, *C. striata*, comes from the Brassfield.

Next I notice the names Micromitra (Paterina) and Obolus, which we apply only to pre-Chazyan species; then Rhinobolus?, which is wholly confined to the Middle Silurian in America; and, finally, Zygospira, which is a very common Middle and Upper Ordovician genus in America, but occurs also in the typical Richmond and continues upward into the Middle Silurian. However, disregarding one questionable identification of the genus in the Middle Silurian Waldron shale of Indiana, it is a significant fact that Zygospira does not occur in the northern and far western Richmond faunas, and that the post-Richmond occurrences of the genus in North America are confined to the Gun River and Jupiter River formations of Anticosti.

Among the 28 genera cited by Jones as making their first appearance in the Silurian, the first and second to invite attention are Atrypina and Chonetes. Judging from their advent in American sections, I also would include these genera among those confined to rocks of Silurian age. However, in his subsequent brief analysis of the Ellis Bay fauna of Anticosti, in which *Atrypina* n. sp., *Atrypa* (*marginalis*), and *Chonetes* (*primigenius*) appear for the first time, Jones rules the Silurian significance of the first and the last out for America on the ground of "the strong Ordovician aspect" of the associated fossils. But, according to the British record also, Chonetes should have been cited in the following list of genera common to both systems. Reed refers a species from the Drummuck group of Scotland to Chonetes.

Then we come to Dinobolus, which may be confined to the Silurian in Britain, but not in America, where we recognize in all four species, only one of which is a Silurian fossil, the others of Black River and Trenton ages. Next comes Eichwaldia, of which the genotype is a Black River species and now—since we refer the externally reticulated species to Dictyonella—the only representative of the genus in American formations. Dictyonella comprises, so far as known, only Silurian species, the oldest being in the Charleton formation (Richmond) of Anticosti, the second in the Noix oolite of the Alexandria group, the third in the Rochester shale, and three others in higher beds of the Niagaran. Finally, there is Meristella, which is included in the list with a query because it "has been doubtfully identified from the Ordovician." Anything even suggesting Meristella has never been reported from American rocks of Ordovician or even of Richmond age. The American representatives of the remaining 23 genera of the list agree with their British relatives

in delaying their first appearance to the Silurian. The several types agree also fairly well in the order of their appearance. However, it is to be noted that all of them appear in both countries in beds that we refer to the Middle Silurian.

The preceding list is followed by another, citing 32 genera that have representatives in both systems. The testimony of these brachiopods as recorded in the rocks on the two sides of the Atlantic agrees in the main. As exceptions I would mention Leptella, which is not known to range above the Middle Chazyan in America; also, Atrypa, Bilobites, Meristina, Hindella, Stropheodonta, and Strophonella, none of which appears in America beneath the Upper Medinan or the Clinton; and, if we except unusually early occurrences in the Richmondian Charleton formation of Anticosti, we might add also Hyattidina, Rhipidomella, and Schuchertella. In view of these differences from the reported range of the genera in Britain, I do not see how we can escape the conviction that either a considerable number of genera of brachiopods appeared much earlier in Europe than in America or that beds there referred to the Ordovician would here be placed in the Silurian.

In his effort to establish the age significance of the trilobite genera, Professor Jones follows the same plan employed in treating the brachiopods. First he gives a list of 30 Ordovician genera selected from those that he says "do not ascend into the Silurian." Unfortunately, 12 of these genera have no unquestionable representatives in America, and at least 7 of the remainder are confined in America, and perhaps in part also in Britain, to older beds than the Mohawkian. Named in the order of their appearance in American formations, these are: Menocephalus, Apatocephalus, and Shumardia, which are confined to pre-Chazyan formations, and Agnostus, Nieszkowskia, Pliomera, and Telephus, none of which is found in America above the top of the Chazyan. The list, therefore, includes 19 genera that have no direct bearing on our problem; and of this number, 7 may indicate differences in the vertical range of the genera in the two countries. The 11 remaining genera, however, range to higher levels in America, and so may justly be claimed as bearing on the questions at issue. Regarding them the record of their respective occurrences on the two sides of the Atlantic shows only two or three striking differences.

For instance, Amphilichas, which, prior to the Richmond, was confined to Atlantic faunas, extended its geographic range both to the south and the north during the time of the Richmond, two fine species of this genus being included in southern faunas of that age in Ohio and Indiana and two very large species in a northern fauna that invaded as far south

as central Colorado. The genus then continued to live in southern waters to about the middle of Alexandrian time, this being indicated by a new species found in southern Illinois, with typical Lichas, Thlipsura, and two species each of Whitfieldella and Rhynchotreta, in a thin bed of limestone belonging to the Edgewood formation. But the Edgewood is most probably not younger than beds referred to the Upper Bala in Britain. The significance of these occurrences is therefore confused.

Then I may mention Ampyx, which certainly did not become extinct at the close of the Ordovician. Barrande described a species from the Silurian of Bohemia, and Van Ingen named another from the Saint Clair limestone in Arkansas. Professor Jones himself notes the recorded presence of the genus in the Silurian Stockdale shale of Britain; also, Remopleurides, which ranges in America only to the Trenton, but in Europe is still well represented in deposits that I think are of Medinan and probably Upper Medinan age.

Only three genera of trilobites are mentioned as making their first appearance in the Silurian: Youngia, Deiophan, and Phacopidella. The first of these is not recognized in this country. The second is suggested in one of the Richmond formations of Iowa and is represented by good species in the Brassfield and in both northern and southern faunas of Niagaran age. Deiophon seems, however, to have occurred also in Europe during or after the Richmond, but before the Clinton, this being indicated by a new species from the Leptæna limestone recently described by Warburg. The Leptæna limestone correlates with the Keisley limestone of England, and both are referred to the Ordovician by European paleontologists. So far as known, Phacopidella is confined in America to Upper Medinan and Clinton formations.

Finally, we may consider the list of 16 genera of trilobites said to occur in both systems. Here the recorded occurrences on the two sides of the Atlantic indicate some striking differences. First, there is Corydocephalus, or, rather, Trochurus. In America we have many species of this genus, but none of them is older than the Clinton, and the genus is similarly limited below in Bohemia. However, it seems probable that the indicated difference in occurrence is occasioned, at least partly, by the mistaken application of the name Corydocephalus to Ordovician species that are more properly referable to the genus Hemiarges, which also is represented by numerous species in America and here ranges upward from the Lowville to the Brassfield. Lichas s. s. (= Metopolichas) also is well represented in American deposits, but all the species found here occur in younger beds than the top of the Richmond. Platylichas, strictly speaking, is not represented among our Ordovician Lichadidæ,

and it is doubtful that any of our Silurian species is properly referable to this genus. If, then, we were to standardize the age significance of the genera of Lichadidæ according to their vertical distribution in the American succession, both Amphilichas and Hemiarges would have to be included with the genera that occur in both systems, whereas Lichas s. s. and Trochurus would be among the genera that are confined to the Silurian, which is quite different from the assignments of these genera in Professor Jones's lists. The real difference is that in the American standard all four of the mentioned Lichadidæ give the impression of being moved upward in the scale.

The case of Staurocephalus is very similar. In America, the same as in Bohemia, this genus does not occur beneath the Upper Clinton. In Britain and Sweden it is said to range downward into the Ordovician. I doubt the propriety of permitting it to do so. Cheirurus s. s. also is confined in America to unquestionably Silurian rocks. The genus does not range downward even so far as the Medinan. Like the Lichadidæ, these two genera also are moved to higher stages in America than is given them in the British succession.

Of precisely similar significance is the fact that in the Upper Leptæna limestone of Sweden, which is correlated on excellent specific evidence with the Borkholm and Lyckholm of Russia, the Keisley limestone of England, and the Kildare limestone of Ireland, we find typical representatives of the genera Lichas, Dicranopeltis, Trochurus, Dicranogmus, Deiphon, and Cheirurus, all of which make their first appearance in America in the Brassfield or in some succeeding zone of the Clinton. According to the American trilobite succession, therefore, the Upper Leptæna limestone and its correlates would be referred to the Silurian and not to the Ordovician.

All this contradictory evidence shows there is something wrong. Either the comparable things did not exist at even approximately the same times on the two sides of the Atlantic or deposits with like faunas and probably of like ages have been referred to one system in Europe and to another in America. In the present case this difference has existed from the beginning of our science to the present day. As I see it, the first of these alternatives bears a small part of the blame, but most of it falls on the second.

DIFFERENCE IN METHODS AND ORIGINAL PRACTICE RATHER THAN IN CORRELATION OF HORIZONS

In concluding my direct comments on Professor Jones' paper, it seems, after the preceding discussion of the evidence afforded by the genera of

brachiopods and trilobites, unnecessary to again analyze his faunal evidence when it is applied to the several formations. In effect I have already refuted his conclusions in so far as they bear on the *proper classification* of the Richmondian and Alexandrian formations in Anticosti and elsewhere. This definite statement is not to be understood as implying that his correlation of the Richmond with European formations that are generally referred to the "Upper Bala" is wholly wrong. On the contrary, I quite agree with him in regarding these possible, though not probable, correlates of the Richmond as mainly if not entirely older than the base of the Lower Llandovery. What I do mean to say is that, in my opinion, the base of the Lower Llandovery should not be set as the absolute basal limit of the Silurian system. It is not the best place to draw the boundary, and it does not correspond to any clearly defined plane in the American succession that would there be regarded as a proper line of division between the Ordovician and Silurian systems.

If the faunal evidence is to be given the place of honor among the various criteria employed in the settlement of this controversy, why should the clearly substantiated American faunal succession be ignored and set aside, in favor of the less certainly established British succession? Really, when we come down to the bare facts and forget preconceptions as to which faunal association may be accepted as an Ordovician one and which as a Silurian one, what are the grounds on which rests the unqualified European decision that the Upper Leptæna and Keisley limestones belong on the Ordovician side of the boundary and not on the Silurian side? Surely the actual stratigraphic relations of these isolated patches of limestone to either the typical Bala or the typical Llandovery have not been positively established.

In Britain, apparently, any limestone found next below a Llandovery-like series of sandstones and shales that carry early types of Monograptus is Bala and therefore Ordovician. And when the stratigraphic relations of the limestone are not clearly indicated, but the preponderant trend of its fossil contents favors alliance with Bala faunas rather than Wenlock faunas, then the patch of limestone is called Bala or at least Upper Bala. The possibility that isolated patches of limestone like the Keisley might represent a calcareous contemporary of some part of the Lower Llandovery, or that they represent local deposits intermediate in age and position between the top of the typical Bala and the base of the typical Llandovery, seems not to have been seriously considered by British stratigraphers; and yet they have known for more than three-quarters of a century that the contact between the two systems is unconformable in Wales. Besides, the "shelly" facies of Llandovery time is so poorly de-

veloped in Britain that it is impossible to gain anything at all comparable to the just conception of the marine life of the time that one finds in the Silurian deposits of Bohemia and America.

Under these and other contributing circumstances, it is not surprising that the British paleontologists generally failed to appreciate the true significance of relatively small changes in fossil faunas in the measuring of geologic time. Such changes were interpreted as local variations in the character of the life of contemporaneous waters. It had not yet been shown that some of the added elements in these modified Bala faunas were new invaders that occurred elsewhere only in higher positions in the succession of life zones than they assigned to them. Nor did they recognize the probability of the more familiar forms in these modified faunas being residuals of older faunal associations. Moreover, the British geologists of the past two generations, in common with those of all other nations, had no adequate conception of the unstable nature of the earth's crust, nor of the consequent frequent shifting of the epicontinental seas, or of their average small size at any given geologic time; nor did they see the need of inquiring very closely into both the geographic and genetic origin of the fossil faunas or into the probable means by which their migration from province to province became possible. Such conceptions and investigations have become prevalent among the leading American stratigraphic paleontologists because they are based on logical reasoning, and more particularly because the results of their application are more satisfactory, more definite, and more lasting. As I see no reason to doubt that the physical conditions during the Paleozoic ages were essentially the same in Europe as we are finding them to have been in America, I venture to recommend a fair trial of the newer American methods to my European friends.

PERSISTENCE OF THE NORTHERN ATLANTIC ORDOVICIAN FAUNA IN THE GIRVAN SEQUENCE OF DEPOSITS

The fauna of the Drummuck group in the Girvan District of Scotland, as described, consists of an extraordinary association of contradictory species. If really a single contemporaneous fauna and Ordovician, then it must be very late. Possibly it is of Richmond or younger age, because it introduces forms like Chonetes, Schuchertella, Rhipidomella, Strophonella, Stropheodonta, Whitfieldella?, Meristella?, and varieties of *Dalmanella elegantula* and *Rhynchotreta cuneata*, all of which suggest late or post-Medinan Silurian rather than Ordovician alliances. However, assuming it is one fauna, it is probably older than the Keisley, the proportion of hold-over Ordovician types being greater than in the Keisley fauna.

In studying the Girvan trilobite and brachiopod faunas as given in the monographs by Reed, I am impressed with another fact that doubtless shares in the responsibility for the evident British disinclination to draw the boundary between the Ordovician and the Silurian beneath any beds they have assigned to the Bala, namely, beginning with the Stinchar limestone and passing on upward through the Balclatchie, Whitehouse, and Drummuck groups and after noting many changes in the character of the successive faunas, I am presently struck by the persistence of some of the generic types of trilobites, among them particularly Agnostus, Ampyx, Lonchodomus, Remopleurides, and Harpes. In American Ordovician formations these genera are almost entirely confined to faunas that are regarded as having invaded from the Atlantic side. Except a Harpes found in the Kimmswick limestone fauna whose origin is unknown, none of the Ordovician faunas of definitely determined southern origin in the west Appalachian and Mississippi Valley regions contain species of the mentioned genera. Evidently their home was in the northern Atlantic realm; and, judging from the record in Girvan, they persisted there or in dependencies at least to and probably after the end of what we call Ordovician time. Unfortunately, this conclusion can not be substantiated by the American record, the Atlantic part of which is a blank from the close of the Trenton on to the Richmond, with which it again proceeds, with minor interruptions, to the close of the Silurian. However, it is this northern Atlantic persistence of well known Ordovician genera of trilobites, together with species of other classes which also have strongly indicated Ordovician antecedents, that is mainly responsible for the antagonistic attitude of European paleontologists to the transfer of the Upper Leptæna limestone of Sweden and its correlates in Russia, Norway, Britain, and Ireland from the lower to the upper side of the Ordovician-Silurian boundary. Their minds are prejudiced by preceding habit and conceptions, and it is the same kind of prejudice that lies at the base of the American opposition to my views as to the proper position of the Richmond. The latter is put forth by those who either forget or do not know that even the typical Upper Medinan fauna still includes a sufficient proportion of species with strong Ordovician affiliations to completely dominate its aspect as a whole;[16] also, they either do not know or choose to ignore the discordant evidence above outlined as to the range of genera that are credited to both systems in Europe, but do not appear in American rocks before the Brassfield or in later Middle Silurian faunas. What shall we do about it?

[16] See list, p. 344.

The Ontarian of America not the same as the Silurian of Europe

Though it is perfectly true that British geologists initiated and established the fundamentals of Paleozoic stratigraphy in not only their own country, but for Europe generally, it is no less a fact that the pioneer geologists of the New York Survey, working independently, were only a few years behind their British contemporaries in publishing a really much better classification of the Paleozoic rocks of their State. In the present connection this early effort is particularly notable from the fact that it recognized the high importance of the separation of the formations assigned to the "Ontario division." Moreover, the Ontario division included precisely that part of the column for which in recent years we adopted the British term Silurian, as restricted by Lapworth in 1879. But the original New York designation for the Silurian was not entirely abandoned by American geologists. In fact, J. D. Dana in 1890 proposed to revive the term in the form Ontarian system, and nine years later Clarke and Schuchert preferred "Ontaric system" in place of Silurian, as restricted by Lapworth. Although various authors have followed Clarke and Schuchert in giving preference to the term Ontaric, which, moreover, has been for the past 25 years and is still the official designation of the system in the publications of the New York Survey, I have so far declined to do so, because Lapworth's compromise solution of the Murchison-Sedgwick controversy seemed a fairer and in other respects a more commendable course to follow.

But when Lapworth cut the formerly joined Lower and Upper Silurian twins apart "at the base of the Lower Llandovery" he did not at the same time assure perpetual freedom from future boundary uncertainties and troubles; nor would such assurance be desirable or possible of sustainment if our science is to grow; and if it grows it must expand, particularly by filling in the "lost" or previously unplaced pages of the geologic record. I am already convinced that Professor Jones and his associates in Wales have added many beds to the base and into the mass of the Lower Llandovery that Lapworth did not know of in 1879; and if the Llandovery is permitted to expand downward, then the system also must be allowed to incorporate such parts of the uncharted intervening "No-man's-land" as the legitimate upward growth of the underlying Ordovician system permits. Here, too, let me remark that if the interests of the science justified Lapworth's restriction of the Silurian, then we must concede the same right to others who have similarly warranted designs on the Ordovician system.

Though desiring to save and continue using all four of the British systemic names—Cambrian, Ordovician, Silurian, and Devonian—in my classification of the American rocks, I can not do so without the permission to modify their original meanings as may be demanded by advance in knowledge. This permit should grant the right of modification (1) by addition of new or previously misplaced beds to top or bottom; (2) by transferal of unessential terminal units from one system to another; and (3) by intercalation of new units within their boundaries or of combinations of units of major grade between them. As I view it, systems and series are to be treated as we do genera in systematic zoology. In revising a genus the genotype is the sole part that must remain. In the other case some faunal concept is typical of the system; and this typical part must remain. In Britain the Silurian is typified by the Wenlock; in America by the Niagaran. After that, let the chips fall as advance in knowledge may direct.

If the separation of the two systems were carried out in America as it was done originally by Lapworth and as it is being done today in Britain and northern Europe generally; and if the Keisley limestone of England and the Upper Leptæna limestone of Sweden are really older than the base of the Lower Llandovery and for that reason to be regarded as Ordovician; and, again, if the first or the last occurrences of at least 13 genera of trilobites and 6 genera of brachiopods[17] on the two sides of the Atlantic are nearly contemporaneous, or at least fall into the same serial division of the system to which in the one case their first and in the other their last remains are referred, then we would have to cut off *our* Silurian at the base of the Clinton and put the whole of the Medinan, including the Brassfield, down into the Ordovician! That, I believe, would be too bitter a pill for Americans to swallow.

Must we, or, rather, should we, submit to this, for us, reactionary, not to say revolutionary, process? However much it would help in producing harmony between European and American views and practices, we should before answering in the affirmative first consider whether submission would work toward the promotion of the interests of our science. I think it too reactionary and too great a sacrifice of hard-won ground. Besides, such reactionary, one-sided adjustments can never be permanent. Sooner or later the patched-up truce is broken, and we have the fight all over again. Furthermore, relatively slight changes in the viewpoints and methods of the opposition would insure just as much harmony, make identification of fossil zones in this case easier and more certain, permit

[17] These numbers include only selections from lists given by Professor Jones in his paper on the Ordovician-Silurian boundary.

more general substitution of definite physical boundaries that are possible only under the application of the criteria of diastrophism for the necessarily indefinite boundaries attainable through purely paleontological criteria, and correspondingly improve our paleogeographic maps.

The natural Boundary as indicated in America

In the course of many years of work in the Appalachian Valley, from New York on the north and Alabama on the south, I have seen many good exposures of the contact between the Ordovician and Silurian systems as defined by me. In none of them did I experience much trouble in finally putting my finger on the contact itself. Being an unconformable contact, mainly by overlap, there is much variation in the ages of the beds making the contact. Where the break is greatest the Silurian usually begins with a thick and often conglomeratic sandstone of Upper Medinan age. This commonly rests on the more or less eroded surface of the Martinsburg shale. As a rule, fossils are wanting in both formations, but the physical break is clearly indicated. Where the break is least, as in the gap south of Reedsville, Pennsylvania, shales corresponding in age to the upper part of the Martinsburg are succeeded by a gray sandstone—the Oswego—and this by the Juniata, a great mass of red sandy shale or shaly sandstone, the lower 300 or 400 feet of which is full of quartz pebbles. This unfossiliferous red formation passes northwardly into the Lower Medina or Queenston shale of western New York, and the latter, when traced to the north and west in Ontario, finally passes laterally into abundantly fossiliferous Richmond formations. At other localities in the Appalachian Valley, notably in southwestern Virginia, east Tennessee, and Alabama, the Oswego is absent and the Richmond consists of fossiliferous, reddish and often sandy marine deposits that rest on fossiliferous beds of the age of the lower, Fairview, division of the Maysville group. In some places the lithic characters of the latter are quite different from those of the Richmond; in other localities both may be reddish and sandy, and then one needs a close acquaintance with the fossils before success in locating the actual contact is possible. On the other hand, in Alabama, where the hiatus at the top of the Ordovician expands locally so that Middle Devonian beds are in contact with Middle Ordovician formations, there are good exposures in which an Ordovician limestone is succeeded by sandy deposits of Richmond age so similar in character to next overlying Clinton beds that even very closely observing stratigraphers have failed to note the presence of the Richmond. Here, again, the contact is not readily located without the aid of fossils.

On the flanks of the Cincinnati dome broad sheets of Richmond formations rest on similarly broad sheets of Maysville, but the unevenness of the contact between the two and its overlapping nature are readily noticeable to anyone intimately acquainted with the distinctive faunal zones of the two series of deposits. The task is much easier in central Tennessee, where the Fairview or Leipers division of the Maysville group is broadly distributed, but the Upper, or McMillan, division absent and the Richmond deposits are confined to narrow sloughlike embayments. Here, then, we have indubitable evidence of warping of the surface immediately preceding the Richmond. In the Mississippi Valley proper the Richmond rests on Trenton or older formations, and the same is true for all western North America from the Rio Grande to Alaska. Evidently the Richmond represents a time of extraordinarily wide transgressions and stratigraphic overlaps following a long period of emergence and, perhaps intervening, diastrophic activity.

The natural Break in the Anticosti Island Section

Whether strictly true or not, all geologists who have studied the well exposed section of Anticosti Island agree in regarding the section beginning with the English Head formation as containing "no stratigraphic break," and hence as "complete from base to summit."[18] Now, since the two lower formations, the English Head and the Charleton, were formerly recognized as "Hudson River" and more recently, and doubtless more correctly, as of Richmond age, and as the Clinton age of the succeeding Gun River and Jupiter River formations is undeniably established, it follows that the accepted absence of any break in this sequence of beds means that in Anticosti Island we have the complete local sedimentary and faunal records of the concerned geological ages. Further, since the Clinton and its correlates belong in the Silurian system and the Richmond is referred by many geologists to the top of the preceding system, it follows that in Anticosti the two systems are inseparably bound together by passage beds and faunas.

Nothing comparable to this provisionally conceded continuity of deposition exists elsewhere in America, and I very much doubt that such conditions exist in Europe. In the Ohio and Mississippi valleys the varying sequence of Richmond deposits suggest a number of probably short interruptions of sedimentation, and some of these were accompanied by land surface tilting and consequent great changes in the direction from which the seas and faunas invaded the continental basins.

[18] W. H. Twenhofel: Canada Dept. Mines, Mus. Bull. No. 3, 1914. p. 2.

Oscillation and more or less local emergence occurred also at the close of the Richmond and during the course of Upper Medinan, or Alexandria, and Clinton times; but none of these movements, paleogeographic changes, and faunal breaks are comparable in magnitude and stratigraphic significance to the break at the base of the Richmond. It is only here and there that they are so sharply indicated by physical criteria that one can place a finger on the actual plane of the break; and when it is readily noticeable, then it usually is because some part of the known sequence is missing. On the other hand, as in the finely exposed section between Lewistown and Reedsville, Pennsylvania, neither I nor other experienced stratigraphers could locate the boundary between the Juniata and the Tuscarora sandstones within an apparently transitional zone of 50 feet thickness. The facts are quite different with the base of the Richmond. So far as my experience goes, this boundary is always sharply drawn.

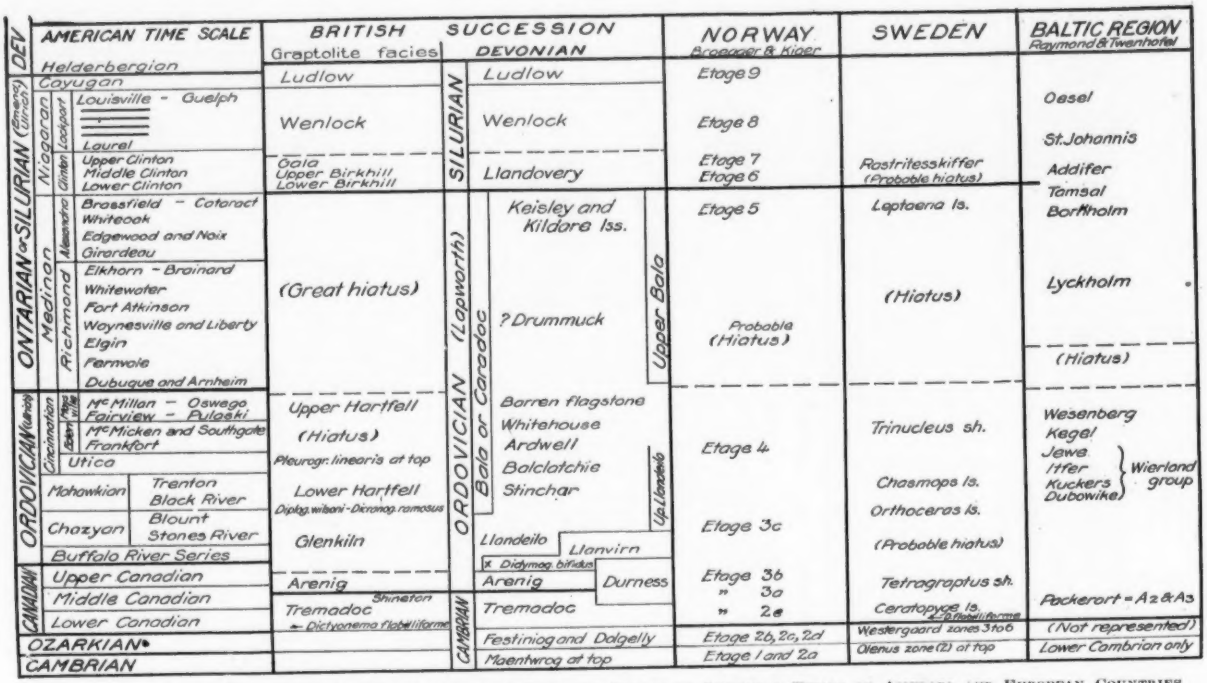
In Anticosti Island, also, the base of the Richmond seems to be sharply delimited by lithologic and faunal differences from the underlying black graptolitic Macasty shale. However indefinite the boundaries between the succeeding formations on the island may be, it is altogether unlikely that good exposures of the contact between the Macasty and the English Head formations would leave any question in the mind of the observer as to just where the boundary between the two should be drawn. Moreover, this contact must represent a hiatus of considerable time value. This is indicated by the faunule of five species known from the Macasty. Among them is the graptolite *Climacograptus spiniferus,* described from lower Trenton occurrences in New York; also *Leptobolus insignis,* a widely distributed shell found elsewhere only in beds of Utica or late Trenton age. Of the remaining three species only the *Triarthrus becki macastyensis* gives any suggestion as to the age of the Macasty. So far as known, Triarthrus is confined to formations beneath the middle Eden. Therefore, according to the fossil evidence, the Macasty should be of late Trenton or Utica age. The hiatus then represents all, or at least most, of the Cincinnatian series.

Desirability of Adjustment between European and American Viewpoints

In America, as I have endeavored to show, the base of the Richmond is everywhere readily and definitely determinable, and therefore a most practical systemic boundary. I believe, also, that a corresponding and equally practical boundary is to be found in northern Europe. That a

Heavy horizontal lines indicate boundaries between systems. In the American column only the Medinan and Cincinnatian series are subdivided into formational units.

CORRELATION TABLE



CORRELATION TABLE SHOWING CURRENT DIFFERENCES IN DEFINING PALEOZOIC SYSTEMIC TERMS IN AMERICA AND EUROPEAN COUNTRIES

Heavy horizontal lines indicate boundaries between systems. In the American column only the Medinan and Cincinnatian series are subdivided into formational units.

stratigraphic break due to preceding surface warping is indicated in the Baltic region at the base of the Russian equivalent of the Richmond was clearly shown in a sketch and statement by Raymond in his paper on "The correlation of the Ordovician strata of the Baltic Basin with those of eastern North America."[19] Speaking of this break, he says: "there is undoubtedly an unconformity at the base of the Lyckholm." The corresponding unconformity should be looked for at or near the base of the Leptæna limestone and the "Brachiopodskiffer" in Sweden, Etage 5 in Norway, and the Keisley and Kildare limestones, the Ashgillian and perhaps other formations of not very dissimilar ages in Great Britain.

I have said that if the European viewpoint were adjusted to the American, and more particularly to my own way of thinking, it would make the identification of fossil zones easier and more definite. In making this statement I had in mind especially the 13 genera of trilobites and the 6 of brachiopods that would be freed from Professor Jones' list of genera common to both systems and whose first appearance, which is so much more important in correlation than last occurrences, would then entitle them to places in the list of genera introduced in the Silurian. Obviously, even these 19 genera would be no small profit, but the gain in number of generic faunal criteria that would thereby be added to the credit of the Silurian fauna when the previously established and the many new genera of all classes are included would more than treble—yes, quadruple—19 genera.[20]

Uncertainties occasioned by residual recurrent Species

Although I have repeatedly discussed the matter, I should not neglect this opportunity to say a few words about the consequences of that bane of the stratigraphical paleontologist, namely, the residual species of genera that were strongly represented in preceding faunas and whose perhaps but slightly modified descendants often mask the true age significance of succeeding associations. In my opinion, the method of determining boundaries of systems and series and of correlating by general aspect of faunas and percentage of generic alliances is responsible for more of the prevailing uncertainties and actual differences in classifying formations than any other cause. Twenty-five to 50 years ago this method seemed if not the only way, then at least the best to reach the truth. Obviously, however, the percentages could not be alike everywhere, so inconsistent results under that method were unavoidable. Besides, that was before the possibilities of the manifold criteria of diastro-

[19] Bull. Mus. Comp. Zool., vol. 56, No. 3, 1916, p. 206, pl. 3.

[20] See tabulated list of genera, p. 335.

phism were even suspected. In Europe the old method persists. In America, however, the more accurate diastrophic criteria are slowly proving their worth as indispensable checks on the faunal evidence. But we are still struggling with remaining error that grew out of the older method and which affected the boundaries of practically every system recognized in modern geology. The Silurian-Devonian border troubles may be said to be past with us. Those between the Devonian and Mississippian and between the latter and the Pennsylvanian are rapidly nearing satisfactory conclusions consistent with the settlement reached in the first case. And now the case of the Ordovician-Silurian boundary is at the crisis. Few realize that the stratigraphic position of from 800 to 1,000 American species alone depends on the outcome.

On preceding occasions I have explained why the general aspect of the Richmond fauna in the Cincinnati region is so much like that of preceding Ordovician faunas. Here it may suffice to ask, What else may be expected under the teachings of evolution and the necessarily consequent belief in the continuity of life? The species and genera, though ever changing, maintained themselves in recognizable form so long as they could, and it is unreasonable to suppose that all the individuals of a well established species or all the species of a strong genus could ever have been simultaneously exterminated. Some always survived somewhere and many left more or less modified descendants. Denial of this could mean only belief in special creations. But, in the face of this unwelcome suggestion, why do paleontologists treat their "guide fossils," especially genera, as though the dates of their advent and exit were immutably fixed by some standard of occurrence with which they are familiar? The many now well known cases of precurrence and recurrence of fossil species and faunas suggest the need of great caution and circumspection in correlating geologic events by means of fossils. They might be made to serve our purposes very well if we knew all about their antecedent and subsequent history, but this desideratum must ever remain an unattainable wish.

First appearances are usually much more dependable for correlation purposes than those set down as the last. Commonly the first appearance of generic types was preceded by some crustal movement that favored utilization of previously impossible means of migration. But the other appearances also may have become possible through similar movements. Besides, we know of many instances in which the first appearance in one region corresponds to the second or perhaps the last in another place. But do not misunderstand me. My intent is only to show that interprovincial correlation by fossils is a much less simple matter

than one would think from current literature. Moreover, as I think the following pages will show, we can do pretty well even with merely generic comparisons. But the process is complicated and laborious, and conclusions are never warranted until we have tried them out by every means known to us. Progress in these investigations is much like the swaying of a pendulum. First the evidence may seem to favor one side, and then, to our disappointment, it swings far to the other side; but presently it hangs practically motionless at some point between the extremes.

Generic faunal Data bearing on the proper Location of the Ordovician-Silurian Boundary in America

GENERAL STATEMENT

Starting from the irrefutable premises that life from its inception has been a continuous process, and that the modification of genera and species has been on the whole slow and gradual, it follows that the differences by which we distinguish the successive fossilized stages of the life of any particular oceanic basin must necessarily become less and less as we approach the boundaries between systems. In its practical application in stratigraphy this principle holds as a rule, but its manifested operation in a given area may often be subjected to disturbance by superposition of very different faunas derived from two or more distinct oceanic basins. Accordingly, it may happen that the first, third, and fifth of a superposed sequence of formations have genetically closely related faunas, whereas those in the second and fourth are very different and either much like each other if they belong to the same realm, or quite unlike if they originated in distinct realms. However near in age the superposed faunas may be, we always find that with the lapse of time some identifiable structural modification in the characteristics of the persisting species or in the composition of the fauna by the introduction of new elements had occurred. But these faunal distinctions can not be determined without making detailed zonal collections of the fossil, and the stratigraphic significance of the distinctions usually are not apparent before it has been suggested by the discovery of physically indicated intervening breaks in the process of sedimentation.

Prior to the discovery of the sharp physical break between the top of the Cayugan and the base of the Keyser formation in Maryland and New York and before it was learned that this hiatus expands greatly in places by absence of late Cayugan and early Helderbergian deposits, it was practically impossible to determine accurately, by means of fossils, just where to draw the line between the Silurian and the Devonian. Essen-

tially the same sorts of difficulties were experienced in the cases of the Devono-Mississippian and the Mississippian-Pennsylvanian boundaries. In each of these cases continuity and transition of deposition was assumed or asserted until the use of diastrophic criteria finally enabled us to locate the actually broken contacts. After this it was no difficult task to work out the range, sequence, and character of the guide fossils that have now become, at least in eastern North America, of definite and unfailing service in recognizing and distinguishing the horizons that belong above the systemic breaks from those beneath the breaks.

Similarly, when I first began to work with the fossils of the Cincinnati and Richmond formations they were supposed to represent an inextricable mixture of Trenton and "Hudson" species. But presently we showed that this was not so. The Trenton species were not strictly the same as their New York relatives. No, they were modified descendants. And the Richmond faunas proved more and more distinct as study and appreciation of their characters progressed. But no one dreamt that the Richmond fauna could be anything later than Ordovician or as young as the Gray sandstone of Oswego. We had not yet learned that in Ontario these Richmond faunal zones passed laterally into the Lower Medina! But remember, also, no one even thought of what the fauna of the time represented by the unfossiliferous Lower Medina in New York and Pennsylvania might be like. Indeed, none even suggested that a marine fauna existed at that time. Moreover, the whole of the Medina was believed to be represented locally in southwestern Ohio by a few inches of sandy rock. Over it came the "Clinton," later called the "Ohio Clinton" and now known as the Brassfield.

Since then our conceptions have changed in radical manner. The Richmond is known to be of the age of the Lower Medina, and its fossils in Ohio represent the southern fauna of that time. And how else than closely similar to the life of preceding Ordovician ages could this Richmond fauna be? Also, it is only what in this day we should expect to find, namely, that the surviving old types in this early Medinan fauna were still too numerous to permit the heralding Clinton types to stand out from the aggregate. It was the Clinton fauna that in 1850 gave us our conception of what a fully developed Silurian fauna should be like; and the same remains true today. But there had to be a beginning; and, as will be shown presently, that beginning was in the Richmond, in which it is much more clearly manifested than in the early stages of the Appalachian Upper Medina faunas. The basis for these statements will be found in the following table of Medinan and Clinton genera, showing the dates of their first known appearance, and in succeeding specific lists

of fossils from the Girardeau limestone of the Mississippi Valley and the Upper Medinan zone of New York and the Appalachian Valley that gave us our first idea of the Medina fauna. It is hoped that these lists will satisfy the demands of the paleontologist for the faunal data which they contend are alone or at least mainly to be depended on in deciding where the boundary between the two systems had best be drawn. As I see it, the fossil evidence is thoroughly in accord with the trend of the physical evidence.

To a considerable extent the long list of genera tabulates the data on which the preceding (pages 316 to 320) detailed discussion of Professor Jones' lists of characteristic Silurian and Ordovician genera of brachiopods and trilobites is based.

The first and subsequent occurrences of the genera in the following list are marked either with an x or by a figure indicating the number of species in the formation. In the last column a dash means that the genus is represented in younger Silurian beds than the Rochester. In the third column E signifies first or last appearance in the Ellis Bay formation and B in the Becsie River formation. For information concerning stratigraphic relations of the Lakemont and Bisher formations, see Silurian volume, Maryland Geological Survey Reports, 1923, pp. 267, 358-361, and 385-391.

TABULATED LIST OF MEDINAN AND CLINTON GENERA SHOWING DATE OF FIRST AND SUBSEQUENT APPEARANCES

Genera.	Medinan.						Clinton.				
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	Richmond.	Girardeau.	Ellis Bay and Bersie River	Edgewood.	Middle Upper Medina in Appalachian region.	Brassfield and Cataract.	Lower and Middle Clinton.	Lower Upper Clinton.	Lakemont—Bisher.	Osgood and St. Clair limestones.	Rochester shale.
Fucoids—Trails											
Arthrophycus							1				
Daedalus							1				
Spongida											
Streptospongia	1										
Anthozoa											
Acervularia						2					
Calapœcia	2		1	1							
Calostylis								x			
Calvinia				1							
Chonophyl'um						1					
Cyathophyllum			B					2			
Cystiphyllum								1			
Diphyphyllum			B			1					
Duncanella										1	
Favosites			x	x		x				x	x
Heliolites						x		x			
Lindströmia						1	x	2			
Lyellia	1		3								—
Lyopora	1		E								
Paleofavosites	1		x			x	x			x	
Striatopora						1					
Ptychophyllum						1					
Thecia						1					1
Zaphrentis	1		x	x		x		x			—
Hydrozoa											
Beatricea	4		E								
Clathrodictyon			x	x							—
Labechia	1									1	1
Graptolitoidea											
Acanthograptus											1
Cactograptus								1			
Cyclograptus											1
Inocaulis											1
Pa'æodictyota								2			2
Retiolites								1			1
Monograptus							1	1			?

TABULATED LIST OF MEDINAN AND CLINTON GENERA SHOWING DATE OF FIRST AND SUBSEQUENT APPEARANCES—Continued

Genera.	Medinan.						Clinton.				
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	Richmond.	Girardeau.	Ellis Bay and Becaie River.	Edgewood.	Middle Upper Medina in Appalachian region.	Brassfield and Catar-act.	Lower and Middle Clinton.	Lower Upper Clinton.	Lakemont—Bisher.	Osgood and St. Clair limestones.	Rochester shale.
Echinodermata											
Allocystites	....	....	....	....	....	....	....	....	....	1	....
Anorthaster	1	....	....	....	....	....	....	....	....	....	....
Apiocystites	....	....	....	....	....	....	....	....	....	....	1
Asaphocrinus	....	....	....	....	....	....	....	....	....	....	2
Austinocrinus	1	....	....	....	....	....	....	....	....	....	....
Brockocystis	....	....	....	....	....	1	....	....	....	....	....
Calceocrinus	....	....	....	....	....	....	....	....	....	....	1
Callocystites	....	....	....	....	....	....	....	....	....	....	2
Canistrocrinus	x	4	....	....	....	....	....	....	....	....	....
Caryocrinus	....	....	....	....	....	....	....	....	....	4	1
Closterocrinus	....	....	....	....	....	....	....	....	1	....	....
Compsocrinus	x	2	....	....	....	....	....	....	....	....	....
Deltacrinus	....	....	....	1	....	....	....	....	....	....	2
Dimerocrinus	....	....	....	....	....	....	....	....	....	....	4
Eucalyptocrinus	....	....	....	....	....	....	....	....	....	....	2
Eucheirocrinus	....	x	....	....	....	....	....	....	....	....	2
Eugasterella	....	....	....	....	....	....	....	....	....	....	1
Gaurocrinus	x	....	....	....	....	....	....	....	....	....	....
Gazacrinus	....	....	....	....	....	....	....	....	....	....	x
Girardeaucrinus	....	x	....	....	....	....	....	....	....	....	....
Gissocrinus?	....	....	....	x	....	....	....	....	....	....	—
Haplocrinus?	....	x	....	....	....	....	....	....	....	....	—
Holocystites	....	....	....	....	....	....	....	....	....	20	....
Homocrinus	....	....	....	....	....	....	....	....	....	....	1
Ichthyocrinus	....	....	....	....	....	....	1	....	....	....	1
Lampterocrinus?	....	....	....	x	....	....	....	....	....	....	—
Lecanocrinus	....	....	....	....	....	....	....	....	....	....	x
Lepadocystis	1	....	....	....	....	....	....	....	....	....	....
Lyriocrinus	....	....	....	....	....	....	....	....	....	....	2
Macrostylocrinus	1	9	....	....	....	....	....	....	....	x	2
Mariocrinus	....	4	....	....	....	....	....	....	....	....	x
Myelodactylus	....	....	....	....	....	....	....	....	....	....	2
Pisocrinus	....	....	....	....	....	....	....	....	....	3	....
Platycrinus?	....	1	....	....	....	....	....	....	....	....	1
Pycnosaccus	....	....	....	....	....	....	....	....	....	....	1
Squamaster	....	....	....	....	....	....	....	....	....	....	1
Stephanocrinus	....	....	....	....	....	....	....	....	....	7	2
Sycaulocrinus	1	....	....	....	....	....	....	....	....	....	....
Trematocystis	....	....	....	....	....	....	....	....	....	2	....
Xenocrinus	3	1	....	....	....	....	....	....	....	....	....
Bryozoa											
Acanthoclema	....	....	....	....	....	....	....	....	....	x	x
Allonema	....	....	E	....	....	....	....	....	....	....	x

TABULATED LIST OF MEDINAN AND CLINTON GENERA SHOWING DATE OF FIRST AND SUBSEQUENT APPEARANCES—Continued

Genera.	Medinan.						Clinton.				
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	Richmond.	Girardeau.	Ellis Bay and Bessie River	Edgewood.	Middle Upper Medina in Appalachian region.	Brassfield and Cataract.	Lower and Middle Clinton.	Lower Upper Clinton.	Lakemont—Bisher.	Osgood and St. Clair limestones.	Rochester shale.
Bryozoa—con.											
Ascodictyon											x
Calloporella	3										
Ceramopora			E							x	x
Chilotrypa							x			x	x
Clathropora						x		x			x
Diamesopora							x				x
Fenestella	1					x	x	x		x	x
Glauconome	1										
Goniotrypa	1										
Hemitrypa						1					
Idiotrypa										1	
Lichenalia	?		E							x	x
Lioclema	2						x			x	x
Lioclemella	4					x				x	x
Loculipora											x
Meekopora								x			x
Paleschara	1							x			x
Phacelopora	2	1									
Pinnatopora		2									—
Polypora								x		x	x
Pseudohornera											x
Ptilodictya	6		E			3	1	1	1		1
Ptiloporella								1		x	x
Ptilotrypa	1										
Rhinopora						1	x				1
Rhombotrypa	3									x	x
Rhopalonaria	1							1			—
Sceptropora	1					1					
Semicoscinium										x	x
Stictotrypa											x
Taeniodictya											x
Thamniscus							x				x
Trematopora	1	2					x			x	x
Species of Bryozoa											
Hallopora cf. elegantula			E			x				x	x
Hallopora magnipora			E			x					
Pachydictya crassa			E	x		x				x	x
Phœnopora ensiformis			E			x					
Stomatopora siluriana			E								?
Brachiopoda											
Anastrophia											x
Atrypa			x	3		x		x		x	x

TABULATED LIST OF MEDINAN AND CLINTON GENERA SHOWING DATE OF FIRST AND SUBSEQUENT APPEARANCES—Continued

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Brachiopoda—con.											
Atrypina	....	....	1	....	....	....	x	....	....	x	x
Bilobites	....	....	....	....	....	....	x	x	....	x	x
Brachiprion	....	....	B	x	....	....	x	x	....	....	x
Camarotœchia (Silurian types)	....	x	B	x	x	x	x	x	x	x	x
Chonetes	1	....	E	....	....	....	x	x	....	....	—
Clintonella	....	....	....	....	....	....	x	....	....	....	....
Clorinda	....	....	....	x	....	....	....	x	x	x	....
Coelospira	....	....	B	....	....	x	x	x	x	....	x
Conchidium	....	....	....	....	?	....	x	x	....	....	—
Cyrtia	....	....	....	....	....	....	....	....	....	x	x
Cyrtina	....	....	....	....	....	....	....	....	....	....	x
Delthyris	....	....	....	....	....	....	....	x	....	....	x
Dictyonella	x	....	....	x	....	x	....	....	....	....	x
Eospirifer	....	....	....	....	....	....	....	x	x	x	x
Hindella	....	....	x	x	....	....	x	....	....	....	....
Homœospira	....	....	....	3	....	....	....	....	....	x	x
Hyattidina	x	....	....	....	....	....	x	....	....	....	....
Nucleospira	....	....	....	....	....	....	....	....	....	x	x
Orthostrophia	....	....	....	....	....	....	....	....	....	x	x
Pentamerus	....	....	....	x	....	....	x	x	....	....	....
Platymerella	....	....	....	....	....	x	....	....	....	....	....
Protozeuga	x	x	....	x	....	....	....	....	....	....	....
Rhipidomella	x	....	x	x	....	x	x	x	x	x	x
Rhynchotreta	....	....	....	6	x	x	....	....	x	x	x
Schizophoria	....	....	....	....	....	....	x	....	....	....	....
Schuchertella	x	x	x	x	....	x	x	x	x	x	x
Stricklandinia	....	....	....	....	....	2	x	x	....	x	x
Stropheodonta	....	....	....	....	....	....	x	x	....	....	x
Strophonella	....	....	....	....	....	x	x	....	x	x	x
Trematospira	....	....	....	....	....	....	....	x	x	....	x
Uncinulus	....	....	....	....	....	x	....	....	....	....	....
Virgiana	....	....	B	....	....	....	?	....	....	....	....
Whitfieldella	....	....	....	3	x	....	x	x	x	x	x
Pelecypoda											
Amphicœlia	....	....	B	....	....	....	....	....	....	....	x
Anoptera	x	....	....	....	....	....	....	....	....	....	....
Bodmania	x	....	....	....	....	....	....	....	....	....	....
Corallidomus	x	....	....	....	....	....	....	....	....	....	....
Cypricardinia	....	....	....	x	....	x	....	....	....	....	x
Leiopteria	....	....	....	....	....	....	....	....	....	....	x
Ortonella	x	....	....	....	....	....	....	....	....	....	....

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Gastropoda											
Callonema	...	...	...	x	...	...	...	...	...	...	—
Diaphorostoma	...	x	E	4	...	...	x	...	x	x	x
Meekospira	x	...	...	...	...	x	...	...	...	...	—
Paleopupa	...	...	...	...	...	x	...	...	...	...	...
Platyceras	...	...	...	...	...	...	...	...	...	x	x
Poleumita	...	...	...	x	...	...	...	...	...	x	—
Strophostylus	...	...	...	...	...	x	...	x	...	x	x
Cephalopoda											
Ascoceras	x	...	E	...	...	...	...	...	...	...	—
Billingsites	x	...	...	...	...	...	...	...	...	...	...
Charactoceras	x	...	...	...	...	...	...	...	...	...	...
Dawsonoceras	x	...	...	x	...	...	...	...	...	x	x
Diestoceras	x	...	...	...	...	...	...	...	...	...	...
Kionoceras	x	...	...	...	...	x	x	...	...	x	x
Ostracoda											
Acronotella	x	...	...	...	...	...	...	...	...	...	...
Beyrichia	...	...	...	...	...	...	x	x	x	...	...
Bolbibollia	...	...	...	...	...	...	1	...	...	...	...
Bonnemaia	...	...	...	...	...	...	...	x	...	...	...
Dizygopleura	...	...	...	...	...	...	...	...	x	...	x
Klœdenia	...	...	...	...	...	...	x	x	x	...	x
Mastigobolbina	...	...	...	...	...	...	x	x	...	...	...
Parœchmina	...	...	...	...	...	...	x	x	x	...	x
Plethobolbina	...	...	...	...	...	...	x	x	...	...	...
Thlipsura	...	...	...	x	...	x	...	...	...	...	—
Zygobolba	...	...	...	...	...	...	19	...	...	...	...
Zygobolbina	...	...	...	...	...	...	x	...	...	...	...
Zygosella	...	...	...	...	...	...	x	x	...	...	...
Trilobita											
Aretinurus	...	...	...	...	...	...	x	...	...	2	1
Brachyaspis	x	...	...	...	...	...	...	...	...	...	...
Calymenella	...	...	...	...	...	...	1	...	...	1	...
Cheirurus	...	...	...	...	...	...	...	...	...	x	x
Dalmanites	...	...	...	...	...	x	...	x	x	x	x
Dalmanitina	...	...	...	x	...	...	...	...	...	x	...
Deiophon	?	...	...	...	...	x	...	...	...	x	x
Dicranopeltis	...	...	...	...	...	...	...	...	...	10	...
Ectenaspis	1	...	...	...	...	...	...	...	...	...	...
Homalonotus	...	...	...	...	...	...	...	x	x	...	x
Lichas	...	...	...	x	...	x	...	...	...	x	x
Liocalymene	...	...	...	...	...	...	1	x	...	...	...
Phacopidella	...	...	...	...	x	x	x	...	...	...	...
Phacops	...	...	...	...	...	x	...	...	...	...	...
Staurocephalus	...	...	...	...	...	...	...	...	...	x	...

TABULATED LIST OF MEDINAN AND CLINTON GENERA SHOWING DATE OF FIRST AND SUBSEQUENT APPEARANCES—Continued

Genera.	Medinan.						Clinton.				
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
	Richmond.	Girardeau.	Ellis Bay and Beesie River	Edgewood.	Middle Upper Medina in Appalachian region.	Brassfield and Cataract.	Lower and Middle Clinton.	Lower Upper Clinton.	Lakemont—Bisher.	Osgood and St. Clair limestones.	Rochester shale.
Trilobita—con.											
Synhomalonotus	x	....	....	....	....	....	....	....	....	....	....
Trochurus	....	....	....	....	....	....	....	....	....	11	....
Miscellaneous											
Ceratiocaris	....	....	....	....	....	....	....	....	....	....	x
Coleolus	1	....	....	....	....	....	....	....	....	....	....
Megalograptus	1	....	....	....	....	....	....	....	....	....	....
First appearances	55	8	13	15	2	20	23	12	2	20	25

COMMENTS ON FACTS BROUGHT OUT IN FOREGOING TABULATION

Approximately only 10 or possibly 12 of 126 genera in Middle and Upper Trenton formations in Kentucky and Tennessee do not pass into overlying Cincinnatian formations.

Out of the Eden fauna of 212 species, 161 do not pass into the overlying beds of the Maysville group. However, of the 127 Eden genera only 5 fail to persist to the Maysville.

The Maysville fauna consists of 436 species, of which only 33 other than "fucoids and trails" pass across the boundary into the Richmond; but the generic break is of much inferior grade, only 63 out of the 173 Maysville genera having failed to pass the line. Accordingly, 110 genera are common to the Maysville and Richmond.

The total known faunas of the Richmond aggregate about 550 species, representing 205 genera. Of the genera, 55 appear for the first time, and 23 of these are now known to be represented by other species in the Brassfield and subsequent faunas. After deducting the 110 genera common to the Richmond and the Maysville and also the 55 newly introduced genera, we have a remainder of 40 genera, made up of surviving representatives of Ordovician generic types that for some unknown reason do not occur in the Maysville group of rocks.

It appears further that of the 150 Ordovician genera that were still in existence at the beginning of the Richmond, 68 continued on into the Brassfield and subsequent ages. Adding the 23 genera introduced in the Richmond and known to have persisted to and beyond the Brassfield, we have a total of 91 Richmond genera that passed up into what we would call Middle Silurian formations. The remaining 114 Ordovician generic types then became, so far as known, extinct at varying stages of the time between the middle of the Richmond and the beginning of the Brassfield.

Next, according to manuscript lists of the faunas as now known, the Girardeau introduces 8 new genera, of which 5 pass into the Brassfield or higher; the Ellis Bay, 7, and the Becsie River, 6, of which 11 continue to or beyond the Brassfield; the Edgewood, 15, of which 14 pass into the Brassfield or higher; the lower half or Whiteoak stage of the Upper Medinan, 2 or perhaps 4, and the second or Brassfield stage of the Upper Medinan, 20. Proceeding, the Lower and Middle Clinton faunas introduce 23 genera, the Lower Upper Clinton or Mastigobolbina zone, 12, and the combined Lakemont, Irondequoit, Osgood, Saint Clair, and Rochester faunas a total of 47 genera. The total fauna of the Lakemont to Rochester formations comprises about 170 genera, of which only about 40 have representatives in pre-Richmond Ordovician faunas. During the Medinan epoch—that is, beginning with the Richmond and closing with the Brassfield—a total of 113 genera were introduced in American early Silurian faunas, and during the Clinton an additional 82 genera.

From these figures it appears that on the basis of first appearances the generic faunal evidence strongly favors beginning the Silurian with the Medinan rather than the Clinton, with which the British and Scandinavian geologists begin it. It also, and even more strongly, favors drawing the boundary at the base of the Richmond than at the base of the Upper Medinan, where it is placed by Grabau, Schuchert, and other American geologists. The contrasting figures are 113 to 82, respectively, in the case of the series, and 55 or, if we add the Ellis Bay first appearances to those of the typical Richmond, 62 to 25, which is the aggregate of the first appearances in the succeeding Becsie, Edgewood, and Whiteoak; or, if we increase the latter number by adding the 20 genera that are introduced in the Brassfield-Cataract fauna, 62 to 45. No preceding Ordovician or succeeding Silurian faunal break is followed by so large a number of first appearances of genera as occurred in the Richmond.

In estimating the stratigraphic significance of these additions to the Richmond fauna, it should not be by percentage of the whole fauna. Even at that, however, the proportion of the new genera to the old is as 62 to about 150, the total number of Richmond genera being approxi-

mately 210. In other words, the new arrivals constitute more than one-fourth of the total number of genera. However the new types came into existence or where they were developed, their presence shows that something important had happened. No other Paleozoic system can show so large a number of new generic introductions during its first epoch as the 113 that made their first appearance in the Medinan series of the American Silurian. The number of new genera in the Lower Ozarkian, the Lower Canadian, the Lower Ordovician (Ulrich), the Lower Devonian, the Lower Mississippian, and the Lower Pennsylvanian is in every instance decidedly less than 113. Take, for example, the Lower Devonian: Opinions differ somewhat as to whether the formations of the Oriskany group should go with the Helderbergian to make up the Lower Devonian or be added to the base of the Middle Devonian. I am inclined to favor the latter arrangement, but even if the Oriskany is left in the lower series, the new generic appearances in the Lower Devonian hardly exceeds 75. The remainder of the fauna is made up of about 100 genera that existed in preceding Silurian and Ordovician times.

On various preceding occasions I have mentioned that, since American geologists generally are agreed in placing the Helderbergian at the base of the Devonian, consistency demands that the next preceding system, whether we call it Silurian or Ontarian, should begin with the Richmond. The two cases are very similar in diastrophic history and also in their faunal relations. The Keyser formation, at the base of the Helderbergian, is most nearly comparable with the Richmond, and the New Scotland-Becraft with the Brassfield and Cataract. Analysis of the Keyser fauna shows that of its 106 genera only 13 are new. Obviously, then, the general aspect of the Keyser fauna is still overwhelmingly Silurian. The New Scotland-Becraft fauna, on the contrary, is as clearly Devonian as that of the Brassfield-Cataract is Silurian.

Specific and generic Alliances of Medinan Faunas

General statement

In the preceding résumé of Schuchert's recent paper (see page 284) I mentioned his making statements respecting the relations of the Richmond fauna to preceding and succeeding faunas that do not agree with my observations. The statements referred to consist of nothing more than the expression of his opinion that the faunal evidence is opposed to the location of the boundary at the base of the Richmond. The groundlessness of this opinion has already been shown in the preceding analysis of the generic evidence. But let us look into the matter somewhat further and from different angles.

So far as I know, Schuchert has expressed no opinion regarding the Girardeau limestone of Missouri and Illinois. However, since he begins the Silurian with the Alexandrian and as Savage begins this group with the Girardeau and refers the underlying Orchard Creek shale to the Richmond, we may assume that Schuchert also draws the systemic boundary between the Orchard Creek and the Girardeau.

My collections from the Orchard Creek comprise 21 species. The association is not closely similar to any other Richmond fauna. In my estimation, this thin formation is slightly younger than the top of the Richmond in Indiana; also, I am inclined to view it as the introductory stage of the Girardeau. The latter belief is based primarily on the positive evidence of community of fossils and secondarily on the negative fact that I could find no satisfactory physical evidence of a break between them. The similarity in fossil contents appears from the following list:

LIST OF FOSSILS FROM THE ORCHARD CREEK SHALE

These fossils were found in the bank of Mississippi River 1¾ miles north of Thebes, Illinois. Of these 21 species the 9 marked with an * occur also in the overlying typical Girardeau limestone.

Streptelasma sp.
Fragments of crinoids suggesting Girardeau species
**Eridotrypa* sp.
Dalmanella aff. *tersa*
**Dalmanella* aff. *corpulenta*
**Dalmanella modesta*
**Rafinesquina mesicosta*
Rafinesquina sp. 2
Strophomena n. sp.
**Protozeuga sulcocarinata*
Zygospira aff. *recurvirostris*
Rhytimya sp.
Psiloconcha sp.
**Pterinea formosa*
**Cyclonema* aff. *cancellatum*
**Cornulites tenuistriatus*
Ceratopsis robusta
Primitiella sp.
**Calymene dubia*
Nileus? sp.
Isotelus sp.

LIST OF FOSSILS FROM THE GIRARDEAU LIMESTONE

The localities are 2 miles north of Cape Girardeau, Missouri, and 2 miles south of Thebes, Illinois.

Ptychocrinus splendens
Ptychocrinus 3 n. sp.
Canistrocrinus, 4 n. sp.
Mariacrinus?, 5 n. sp.
Xenocrinus n. sp.
Macrostylocrinus?, 5 n. sp.
Macrostylocrinus (subgen. with uniserial arms), 4 n. sp.
Haplocrinus? n. sp.
Carpocrinus? n. sp.
Dendrocrinus n. sp.
Protaxocrinus girardeau
Girardeaucrinus subrectus
Eucheirocrinus n. sp.
Cyclocystoides? illinoisensis
Schuchertia ordinaria
Undet. starfishes
Eridotrypa sp.

Monotrypa rectimuralis
Nematopora alternata
Nematopora delicatula
Nematopora fragilis
Nematopora retrorsa
Phacelopora pertenuis
Pinnatopora, 2 n. sp.
Trematopora calloporoidea
Trematopora, 2 n. sp.
Camarotœchia festinata
Dalmanella modesta
Rhynchonella? sp.
Rhynchotrema? illinoisense
Rafinesquina mesicosta
Rafinesquina? delicatula
Lingulops ovata
Protozeuga sulcocarinata
Schuchertella missouriensis
Ctenodonta, 5 species
Clionychia (*Mytilarca*) sp.
Cypricardinia sp.
Psiloconcha sp.
Pterinea formosa
Pterinea n. sp.
Modiolopsis concinna
Modiolopsis n. sp.
Whiteavesia?, 2 n. sp.
Cyclonema aff. *cancellatum*
Holopea, 2 n. sp.
Diaphorostoma immaturum
Phragmolites imbricatus
Prœtus depressus
Calymene dubia
Cyphaspis girardeauensis
Acidaspis halli
Encrinurus deltoideus
Tentaculites incurvus
Cornulites tenuistriatus

Except for the presence of Pinnatopora, Schuchertella, Cypricardinia, and Diaphorostoma and the rather decided Niagaran affinities of the crinoids, the remaining members of this southern fauna of over 80 species are still very strongly suggestive of the Ordovician. On the other hand, however, it will be observed that by increased elimination of the Ordovician types the Middle Silurian affiliations have become proportionately much more prominent than in the Richmond faunas. Still, silurification of the fauna, if I may use this expression, did not progress uniformly in all the basins. This is clearly indicated by the following list of the next younger Upper Medinan fauna as developed in the more clastic rocks of New York and the Appalachian Valley. Evidently, too, the delay in adding Middle Silurian types to the latter is largely accounted for by its development in the north middle Atlantic, in which the southern or Gulf of Mexico Silurian fauna had not yet appeared.

FOSSILS FROM THE MIDDLE OR TYPICAL PART OF THE UPPER MEDINA SANDSTONE AT LOCKPORT, NEW YORK

C = also at Chamberlain, Tennessee; Cg = also at Cumberland Gap, Tennessee; H = also at Hamilton and Flamborough Head, Ontario; X = at all four localities. Of the 44 species here listed 12 occur at Hamilton, 12 at Cumberland Gap, and 8 at Chamberlain.

H *Lioclemella* cf. *ohioensis* and undescribed Richmond species
X *Helopora* cf. *fragilis* Hall
X *Phœnopora explanata* Hall
Cg H *Phœnopora* cf. *constellata* Hall
Orbiculoidea parmulata Hall
Cg C *Rhynchotrema plicata* Hall

Rhynchotrema cf. *increbescens* and *neglecta*
Cg H *Lingula cuneata* Hall
C *Whitfieldella oblata* (Hall)
Cg *Ctenodonta* sp. nov.
C Cg *Cleidophorus* sp. nov.
Cg *Modiolopsis* aff. *valida*
Modiolopsis? sp. undet.
H *Colpomya* aff. *faba* and *sublata*
Cg *Ischyrodonta* sp. 1 aff. *elongata*
Ischyrodonta sp. 2 aff. *truncata*
Ischyrodonta sp. 3 aff. *modioliformis*
H *Ischyrodonta* sp. 4
Ischyrodonta sp. 5
Cg *Orthodesma* (*?Endodesma*) *orthonota* Hall
Orthodesma sp. nov.
Cg H *Endodesma* sp. nov.
Cg H *Rhytimya* sp. nov.
Cyrtodonta sp. nov. aff. *billingsi*
Cg *Cyrtodonta* sp. nov. 2
H *Cyrtodonta* sp. undet. cf. *C. halli* Nettelroth
X *Cyrtodonta?* (n. gen.) *primigenia?* (Hall)
Cyrtodonta? (n. gen.) two new varieties
C Cg *Caritodens* sp. 1
C Cg *Caritodens* sp. 2
Caritodens sp. 3, 4, 5, and 6
Cg *Pleurotomaria* ?? *pervetusta* Hall
Holopea? sp.
Hormotoma? subulata? Hall
Cg *Lophospira litorea* (Hall)
Cg H *Bucanella trilobata* (Conrad)
Orthoceras sp. 1
Orthoceras sp. 2
Oncoceras gibbosum Hall
Leperditia cylindrica (Hall)
Leperditia sp.

ADDITIONAL MIDDLE UPPER MEDINA (WHITEOAK) SANDSTONE FOSSILS FROM CUMBERLAND GAP, TENNESSEE

Diamesopora? sp.
Ramose trepostomata
Lingula sp.
Rhynchotrema? aff. *equiradiata*
Rhynchotrema? aff. *dentata*
Rhynchotrema? aff. *neglecta*
Cleidophorus sp.
Ctenodonta, 2 species
Cyrtodonta, 2 species
Lyrodesma, 2 species
Lyrodesma? or n. gen. et sp.
Psiloconcha sp.
Pterinea, 2 species
Pyrenomoeus sp.
Liospira cf. *affinis*
Calymene sp.
Liocalymene? (pygidium only)

These two supplementing lists contain 65 species, and thus give a much better idea of the general character of the fauna of the time in the Appalachian region than we had heretofore.[21]

The most interesting feature of this fauna is the decidedly Richmondian affinities exhibited by the Pelecypoda, which, moreover, constitute considerably more than a majority of the total number of species. Indeed, this whole assemblage of Pelecypoda might be found in a Richmondian formation without occasioning the least surprise. On the other hand, some of these bivalves, particularly those of the long-ranging gen-

[21] A. W. Grabau: Jour. Geology, vol. 17, 1909, p. 238, gives a list of 27 species "so far obtained from the Medina." This list includes 6 of trails and "fucoids"; also, several that I do not recognize and others that I have not seen in Medina faunas. Of the last, *Uncinulus stricklandi* suggests some error in identification of the species or in the locality label.

era—*Ctenodonta, Cleidophorus, Cyrtodonta,* and *Pterinea*—are, perhaps, as much like their Clinton descendants as they are like certain Richmondian and Trenton species of the same genera. The characteristic ostracod, *Leperditia cylindrica,* also reminds very strongly of a Richmond species, being scarcely distinguishable from *L. cæcigena.*

Many very similar and in part the same species of pelecypods occur in the Edgewood formation of Missouri and Illinois. For this reason and also because they occupy about the same stratigraphic position, I am inclined to correlate the Edgewood and the Whiteoak sandstone of Tennessee with the New York sandstone that supplied the fossils originally described by Hall as the Medina fauna. Regarding the latter, even as extended in the preceding lists, it is important to note that it contains not a single species that would be regarded in Europe as definitely indicative of Silurian. But the Edgewood fauna contains enough of reasonably convincing Silurian types to cause Professor Jones to speak of it as suggesting "overlap of Ordovician and Silurian faunas." However, as I have repeatedly remarked, the genera of the Edgewood fauna that indicate Silurian to him are the forerunners of the now more nearly pure southern Silurian fauna that did not reach Britain before Clinton time. In the meantime it again invaded America during the Brassfield, and on this occasion in so much more accomplished form that Professor Jones accepts the Brassfield as unquestionably Silurian. But even the Brassfield is older than the base of the Llandovery.

After the Clinton the generic additions to the American Silurian faunas of the several oceanic realms are relatively much fewer than in the first half of the period. The total number of genera added in the second half does not exceed 70, and about five-sixths of these are corals, crinoids, cephalopods, and merostomes.

The Edgewood fauna, comprising at least 90 species, reminds considerably of the Girardeau fauna, except that it contains much fewer crinoids and more corals. However, especially among the brachiopods, the number of distinctively Silurian types is increased by addition of species of Homœspira, Clorinda, Rhynchotreta, Whitfieldella, Atrypa, Lichas, Clathrodictyon, and other genera. The corals remind very much of Zone 5 of the Norwegian succession.

The Brassfield and Cataract faunas, with their southern types, some of which did not reach Britain till Wenlock time, were of course freely admitted by Professor Jones into Llandovery, and preferably Upper Llandovery, time. All our Clinton faunas, too, "must, if fossils have any value, be later than the Lower Llandovery." However, the basis for this opinion is not so strong as he thinks, because at least 8 of the 15 genera and species mentioned by him as "from the Lower Clinton of

New York and Appalachian Valley" do not, so far as known to me, occur in the Lower Clinton, and most of the 8 appear with us for the first time in the Upper Clinton. Others, of the remaining 7, among them the Monograptids, occur in both Lower and Upper Clinton, while yet others are subject to doubt because of uncertainty as to their identification and vertical range. It appears, then, that the Lower Clinton is represented in the Lower Llandovery rather than in the Middle or Upper Llandovery. Whether our Middle Clinton is represented in the Llandovery is more doubtful, but there is little, if any, reason to doubt that the Upper Clinton is largely represented in the Upper Llandovery. Indeed, the Rochester member may correlate with the lower part of the Wenlock.

Conclusions

The present inquiry comprises two different, though closely related, problems: First, Which horizon in the American stratigraphic sequence corresponds to the base of the Silurian as defined by Lapworth and accepted, perhaps generally, by European geologists? And, second, Which stratigraphical plane, particularly in America, is the most widely determinable, the best indicated by faunal and physical breaks, and therefore the most practical and the most natural boundary between the Ordovician and Silurian systems?

My conclusion regarding the first problem is that the base of our Clinton corresponds approximately to the base of the Lower Llandovery; hence to the base of the Silurian as defined by Lapworth. Further, that the Keisley limestone of England, the Kildare limestone of Ireland, Zone 5*a* of Norway, the Upper Leptæna limestone of Sweden, and the Borkholm of Russia, all of which are referred to the Ordovician in Europe, correlate with the Upper Medinan of America. The Lyckholm of Russia and its possible, though as yet unrecognized, correlates in the other European countries correspond to the northern facies of our Richmond.

The conclusion in the second problem, after again studying and weighing all the old evidence in the light of recent developments, is, so far as America is concerned, essentially the same as set forth in my 1914 paper on the Ordovician-Silurian boundary. I am still convinced that the Polk Creek shale represents the Upper Hartfell of Britain, and that both are older than the Richmond. The precise relations of the Medinan, including the Richmond, to the Silurian graptolite facies represented in the Blaylock sandstone of Arkansas remain undetermined, though the uncertainties have been lessened by increased probability that the monograptid zone of that formation is of Clinton age. No positive evidence of the existence of Monograptidæ before the close of the Medinan is known.

Finally, the previous conclusion as to the main feature of the problem, namely, which of several possible boundaries is the best from all standpoints, except that of original definition, at which to draw the boundary between the two systems, is again offered, only with greater confidence in its validity than before.

The Silurian system as restricted by Lapworth and now generally defined and used in Britain is decidedly inferior in time value to the other Paleozoic systems. This lack of coordination is especially notable in comparison with the Ordovician system as developed in eastern America, even in the restricted sense in which the latter term is employed by me. Approximate coordination of the two systems and harmony in practice should be attained by adapting the unbalanced European custom to the American practice of over 80 years.

Although diversity of opinion exists in America as to this boundary, it is certain that none of the various positions assigned to it corresponds to the one given it in Britain. On the other hand, there can be no question as to what formations were included in 1842 by the New York State geologists in their Ontario division of the New York system; or what the New York Survey of the present day includes in their Ontaric system; or what Dana included in his Ontarian system. In each of these cases the Ontario, Ontaric, or Ontarian corresponds essentially or exactly with the Silurian system as hitherto defined by me.

Accordingly, then, if the European geologists will not modify their definition of Silurian and Ordovician I prefer to use a distinct set of systemic terms for America.

The reference of European formations of Medinan age to the Silurian or Gotlandian—that is, to the system of which the Wenlock is the most typical part in Britain and the Rochester and Lockport in America—is not without precedent among European geologists. Thus Barrande, in 1856, correlated the Swedish beds of this age with his Etage E in Bohemia. This view had adherents in Sweden, among them Tornquist and Munthe, at least up to 1906, in which year the latter placed not only the Leptæna limestone in the Silurian, but expressed the belief that the underlying Staurocephalus bed marks the natural boundary between the Ordovician and Silurian; also, it is clearly evident from old labels on Borkholm fossils of like age that some of the Russian geologists regarded this formation as "Upper Silurian." It should be remembered, also, that it was during the last decade of the preceding century and the first of the present that the now discredited law of dominance of generic faunal aspect in correlation attained its maximum vogue and when our respect for both the physical and faunal criteria of diastrophism declined to its minimum.

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SANTORINI ERUPTION OF 1925[1]

BY HENRY S. WASHINGTON

(Presented before the Geological Society December 28, 1925)[2]

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INTRODUCTION

Santorini, a medieval Italian corruption of Sant'Irene, the patron saint of Thera, is the name given to a small group of volcanic islands, almost the southernmost of the Grecian archipelago. The geographical position of Giorgios Kameni, at about the center of the group, is latitude 36° 24′ north and longitude 25° 24′ east. The islands lie on the curving

[1] Manuscript received by the Secretary of the Geological Society February 5, 1926.
[2] Preliminary papers have been published in Jour. Washington Acad. Sci., vol. 16, 1926, p. 1, and in Bulletin Volcanologique, vol. 3, 1926.

belt or zone of active or recently extinct volcanoes[3] that extends from Kolantziki[4] (on the coast of Megara, east of the Isthmus of Corinth), through Ægina,[4] Methana,[4] Poros,[4] Milos (with Kimolos, Antimilos, and Polyvos),[5] Santorini,[6] Nisyros,[7] and Kos,[8] to Kalymnos, and probably northwardly through Mount Pagos at Smyrna,[9] to Phocea and Pergamon.[9] The lavas along this volcanic line are much alike and are almost all dacitic and andesitic, with a few basalts. The zone constitutes a well-defined, although small, comagmatic region, which forms an arc or festoon bordering the sunken block of the former Ægean landmass.[10] This arc is similar to the Antillean and Aleutian arcs and those along the east and southeast coasts of Asia, except for a possible difference in origin, the Ægean arc originating, according to Suess, in a subsidence, while the others, according to various authors, were due to pressure from the seaward side. It is, perhaps, worthy of note that in general chemical composition the lavas of the Ægean arc are like those of the Antillean, Aleutian, and east Asian arcs, or at least of their outer sides.[11]

Santorini has become a classic in volcanology, partly because of its citation by von Buch, de Beaumont, and others as an example of the now abandoned theory of "craters of elevation," and because of the monumental work of Fouqué, who describes in great detail and with many illustrations the islands and their eruptions, especially that of 1866-70. I visited the group in March, 1893, and studied the present eruption from the 13th to the 20th of September, 1925, in company with Prof. K. A. Ktenas, of the University of Athens, and Dr. P. Kokkoros. I would extend my thanks to these fellow-geologists and to several friends at Phira for many courtesies and much assistance. Several short notes by Professor Ktenas and others[12] have recently been published, which have been availed of in describing the initial phases of the eruption.

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[3] Friedlaender and Sonder: Zeits. Vulkanologie, vol. 8, 1924, p. 4.

[4] Reiss und Stübel: Ausflug nach Ægina und Methana, Heidelberg, 1867; Washington, Jour. Geol., vol. 2, 1894, p. 789; vol. 3, 1895, pp. 26 and 138.

[5] Ehrenburg: Die Inselgruppe von Milos, Leipzig, 1889; Sonder, Zeits. Vulkanologie, vol. 8, 1925, p. 181.

[6] Fouqué: Santorin et ses Éruptions, Paris, 1879; also, von Seebach, Abhandl. K. Ges. Wiss. Göttingen, vol. 13, 1867, p. 1; Fritsch, Reiss, und Stübel, Santorin, Heidelberg, 1867; Schmidt, Vulkanstudien, Leipzig, 1874, pp. 1-199; Philippson in Hiller von Gaertringen, Thera, Berlin, 1899, vol. 1, pp. 36-82; Neumann und Partsch, Physikalische Geographie von Griechenland, Breslau, 1885, pp. 272-293.

[7] Martelli: Il gruppo eruttivo di Nisiro, Mem. Soc. Ital. dei xl, vol. 20, 1917, p. 79.

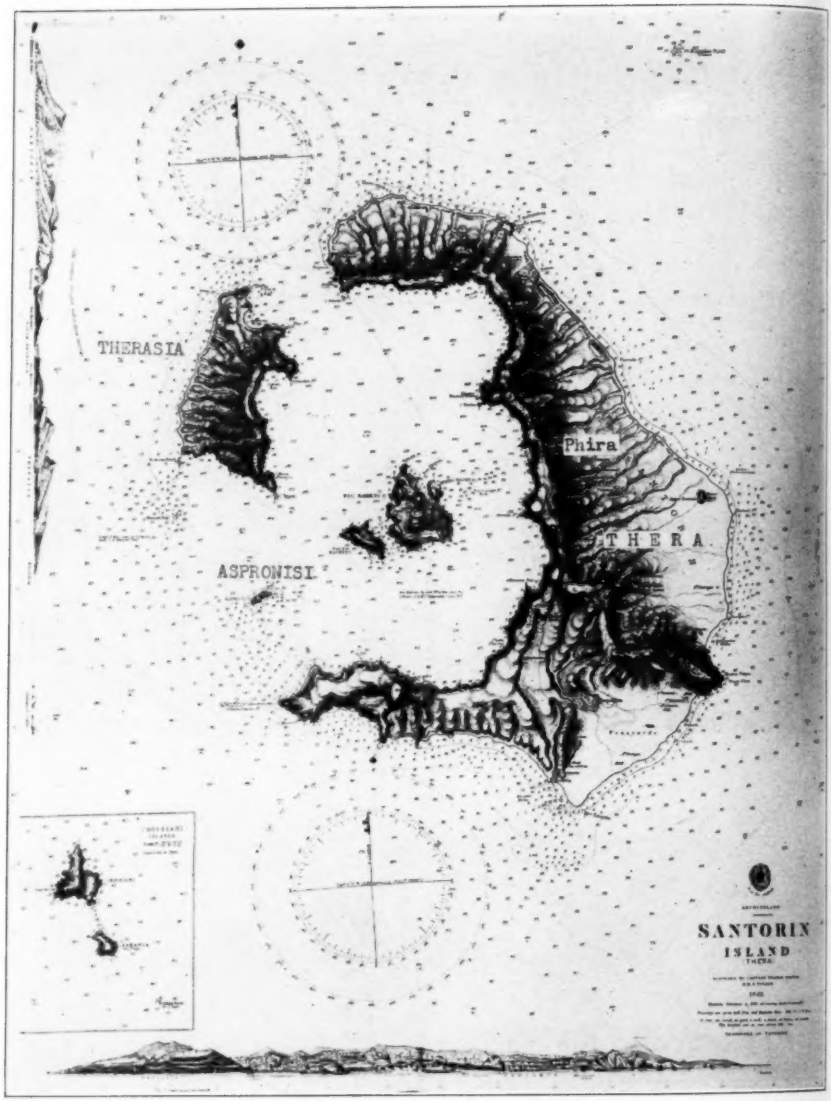
[8] Doelter: Verhandl. geol. Reichsanst. Wien, no. 13, 1875, p. 233; Millosevich, Rend. Accad. Lincei, vol. 21, 1912, p. 304.

[9] Washington: Amer. Jour. Sci., vol. 3, 1897, p. 41.

[10] Suess: The face of the earth (English translation), vol. 1, 1904, p. 344.

[11] Hobbs: Earth evolution. New York, 1921, p. 163.

[12] K. A. Ktenas: C. R. Acad. Sci., vol. 181, 1925, p. 376; G. Georgalas and N. Litsiakas, ditto, p. 425; Ktenas, ditto, p. 518 (map); Ktenas, ditto, p. 563; Lacroix and Ktenas, ditto, p. 893; Kritikos, ditto, p. 921.



MAP OF SANTORINI ISLANDS

From B. A. Chart No. 2043 (corrected to April, 1918). Scale = 1 :200,000.

SANTORINI

PREHISTORIC VOLCANO

Santorini group.—The group of Santorini (plate 9) consists of five or six islands, which are geologically referable to three distinct periods. On the east is the largest island, Thera (= "holy," the ancient name for the group). This is a semicircular crescent, about 15 kilometers from the northern tip to the southern and about 6 kilometers at its widest, southeast part. The western, inner and concave side is a precipitous cliff (figure 1), which reaches a maximum height of 360 meters toward the north, being about 260 meters high at Phira, and lower at the Acro-

FIGURE 1.—*Inner Cliff of Thera*

Taken from Phira, looking north: Merovigli in the background, Skaros on left. Note the interbedded lava-flows and ash beds.

tiri end to the south. Outwardly, it slopes radially down to the sea. The chief town, named Phira, has about 1,000 inhabitants. The main industries of the islands are: an excellent, though rather heavy, wine, esteemed throughout the eastern Mediterranean; pozzolana, from the uppermost bed of pumiceous ash, which is largely exported for the making of hydraulic cement; and fishing.

At the southeast of Thera is the massif of Agios Elias, about 568 meters high, composed of mica schist and marble, as are most of the Cyclades to the north. This massif was the original island, before volcanic activity began. The rest of the island is wholly volcanic, built up of alternating sheets of lava and beds of tuff, crowned by an almost con-

tinuous bed of white ash, that tops all the prehistoric islands. Most of the lavas of Thera (and of Therasia and Aspronisi) are very uniform in character and of subaerial origin, but Fouqué has shown that a few of them, in the region of Acrotiri at the south end, are submarine and of decidedly different petrographical characters.

On the northwest of the group is the smaller island of Therasia, about 6 kilometers long (north to south) and about 2 kilometers wide; it has the same general structure and composition as Thera. On the west-southwest is the islet of Aspronisi (white island), conspicuous for its thick uppermost layer of white pozzolana, from which it derives its name.

These three islands, Thera, Therasia, and Aspronisi, inclose, except for entrances on the northwest and the southwest, an oval lagoon, which measures about 11 kilometers from north to south, and about 7 kilometers from east to west. The greatest depths of this lagoon are in the northern half, slightly more than 200 fathoms, but very considerable up and down movements of the bottom have been noted at different places and at different dates.

According to Fouqué, the original prehistoric island had a low domal form, with a valley running toward the north and a larger one toward the southwest. It would appear to have been well-wooded on its lower slopes, the upper being of barren lava, and it was well cultivated, especially along the southwestern valley.

The formation of the present central lagoon is attributed by Fouqué[13] to an explosion of the original cone, accompanied by a sinking of the central part. Fouqué assumes such a sinking in order to account for a supposed deficiency in the volume of the uppermost, thick stratum of white pumiceous tuff that covers all the three prehistoric islands. I am quite at one with Fouqué as to the explosive origin of the central caldera, but am inclined to think that the apparent deficiency in the amount of material may be accounted for by loss in the surrounding sea, without invoking any subsidence.

The "pozzolana."—The bed of white ash or "pozzolana," which forms the uppermost stratum over most of the area of the three outer islands, attains in places a thickness of 30 meters.[14] It was extensively used for making hydraulic cement in the construction of the Suez Canal, and is now exported in large quantity for the same purpose.

In general it is very slightly grayish white, dazzlingly so *en masse* and in the sun. In by far the greater part is a very fine, loose, white powder, which contains many blocks of white pumice,[15] anorthitic lavas, and

[13] Fouqué: Santorin, pp. 426-433.

[14] For a full description of the pozzolana, see Fouqué, Santorin, pp. 292-297.

[15] Small blocks and fragments of this pumice are often seen floating on the lagoon.

the various kinds of hyalodacites, with very few of schist and marble. I have examined a specimen of the screened material, prepared for export, which was kindly given me by Mr. J. J. Syrigo, the specimen coming from the quarry of Don Petro Syrigo, near Phira. It is mostly an extremely fine white powder of pumiceous material, which contains a small proportion (about 20 per cent) of small (up to 5 millimeters) fragments of whitish pumice, with very few and still smaller ones of the ordinary black lavas. According to Fouqué the pumice contains about 3 per cent of crystals of labradorite, oligoclase, hypersthene, and augite. A little calcium carbonate is also present.

An analysis of an average sample of the pozzolana was made by my assistant, Miss Mary G. Keyes, with the following results.

TABLE 1.—*Analyses of Pozzolana*

	1	2	3
SiO_2	64.88	68.29	71.0
Al_2O_3	12.98	13.67	16.8
Fe_2O_3	3.83	4.03	0.8
FeO	2.30	2.42	n. d.
MgO	1.06	1.12	0.7
CaO	2.95	3.10	0.8
Na_2O	3.16	3.33	7.4
K_2O	2.04	2.15	2.0
H_2O+	4.58	.....	n. d.
H_2O-	0.37	.....	n. d.
CO_2	n. d.	.....	n. d.
TiO_2	1.53	1.61	0.5
P_2O_5	0.22	0.23	n. d.
MnO	0.05	0.05	n. d.
	99.95	100.00	100.0

1. Pozzolana, Syrigo quarry, near Phira, Thera. Keyes, analyst.
2. Pozzolana, Syrigo quarry. Calculated free from H_2O.
3. "Amorphous part of pumice." Thera. Pisani (?) analyst. Fouqué, Santorin, page 296.

The analyses 1 and 2, when compared with those of the fresh lavas (table 2, page 378), show that the pozzolana is a slightly altered ash of the normal Santorini dacite. Fouqué's analysis shows that the glass of the pumice is much more siliceous and of quite different composition.

In the ejection of the enormous amount of pumiceous material (ash and blocks) during the plinian paroxysm that formed the caldera, Santorini is very closely analogous to several other strato-volcanoes with huge calderas, which likewise ejected vast quantities of pumiceous ma-

terial only at the time of the caldera-forming explosion. Of such volcanoes, of which the descriptions are adequate to permit us to recognize the pumiceous character of the ejected material, may be mentioned Vesuvius[16] and Krakatoa,[17] probably Pelée,[18] and possibly Asamayama (1783),[19] Oshima,[20] and Cotopaxi.[21] No formation of pumiceous material seems to have accompanied the formation of the Val del Bove at Etna. Of these volcanoes, Vesuvius, Oshima, and Etna are basaltic, while the lavas of Krakatoa, Pelée, Asamayama (?), and Cotopaxi much resemble chemically those of Santorini.

The origin of these pumiceous materials may be attributed to a probably more or less sudden boiling up of the lava in the throat of the volcano, accompanied by explosions, such as Lacroix has suggested to explain the *nuées ardentes* at Pelée and elsewhere,[22] and with which Fenner compares the explosions that laid down the pumiceous ash beds of the Valley of Ten Thousand Smokes.[23] Indeed, Wolf,[24] cited by Fenner, records what was apparently such an actual boiling over of highly gas-charged lava at Cotopaxi in 1877. The abundant ash that covered Vesuvius in the eruption of 1906 was in part derived from the foaming head of the lava column, but was mostly detrital material, according to Perret,[25] differing in texture from the pumiceous ash of the plinian eruption of 79.

This is not the place to discuss the possible causes of such a sudden and temporary change in the character of the volcanic activity. It should, however, be pointed out that, at Krakatoa and Santorini at least, study of the ejected material shows that crystallization had almost certainly not proceeded far enough[26] to develop sufficient pressure to cause the rapid evolution of gas, according to Morey's[27] application of the "second boiling point." Another cause must be looked for to account for the sudden release of accumulated pressure at Krakatoa and Santorini.

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[16] Johnston-Lavis: Quart. Jour. Geol. Soc. London, vol. 40, 1884, pp. 83-89; Lacroix, Nouv. Arch. Muséum (4), vol. 9, 1907, p. 128.

[17] Verbeek: Uitbarsting van Krakatau, Batavia, 1884, p. 119; Judd, in Rep. Krakatoa Comm., London, 1888, p. 36.

[18] Lacroix: La Montagne Pelée, Paris, 1904, p. 25.

[19] Omori: Bull. Imp. Earthq. Invest. Comm., vol. 6, 1912, p. 111. I can find no petrographical description of the rocks of Asamayama.

[20] Tsuboi: Jour. Coll. Sci. Univ. Tokyo, vol. 18, 1920, p. 15, plate v.

[21] Young: In Reiss und Stübel, Hochgeb. Rep. Ecuador, vol. 2, 1902, pp. 255, 261.

[22] Lacroix: La Montagne Pelée, 1904, pp. 354 ff.

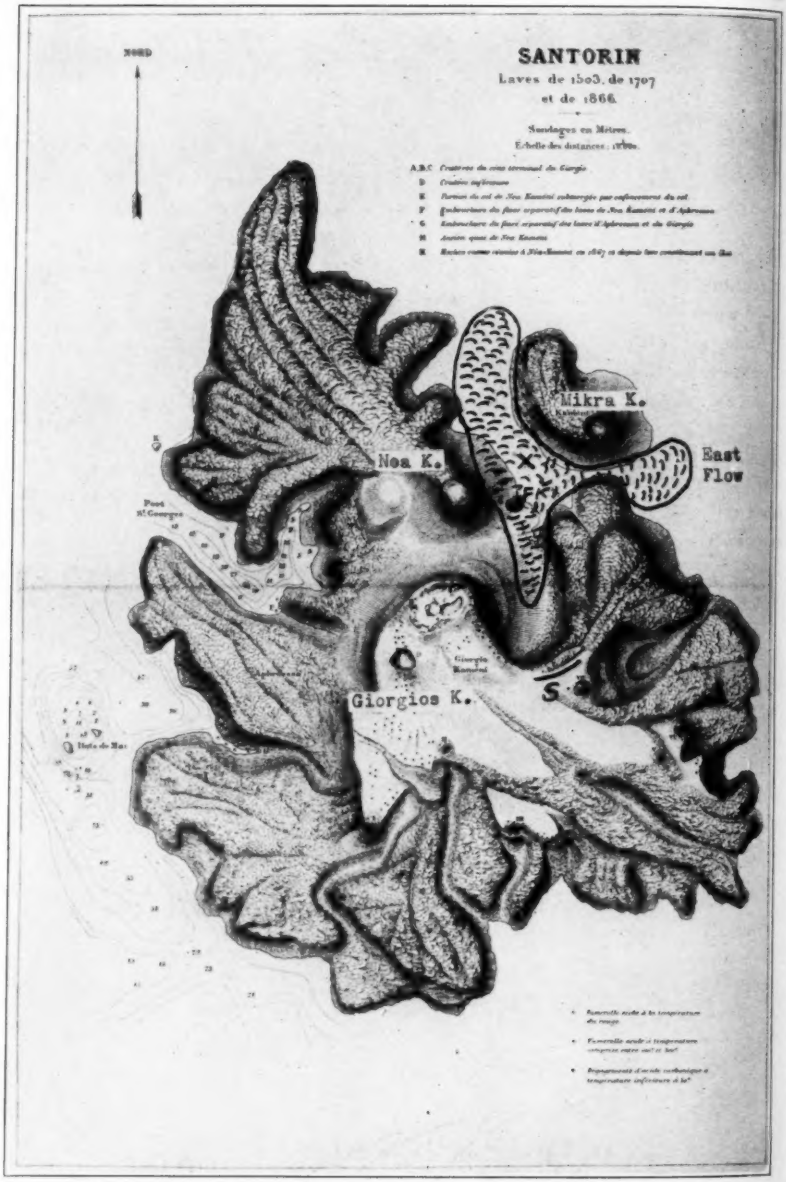
[23] Fenner: Nat. Geog. Soc., tech. papers, no. 1, 1923, pp. 61, 70.

[24] Wolf: Neu. Jahrb., 1877, p. 131.

[25] Perret: The Vesuvius eruption of 1906. Carnegie Publ. no. 339, 1924, p. 89.

[26] Fouqué (page 296) found only 3 per cent of crystals in the Santorini pumice, and the descriptions of Verbeek (page 210) and Judd (page 36) indicate similar percentages in the pumice of Krakatoa.

[27] Morey: Jour. Washington Acad. Sci., vol. 12, 1922, p. 219.



MAP SHOWING THE CENTRAL ISLANDS, EXCEPT PALAIA KAMENI, SEPTEMBER 19, 1925

Based on Fouqué, Santorin, Plate XXIX. Note the initial (×) and later (F. K.) positions of Fouqué Kameni, and the two lava-flows between Mikra and, respectively, Nea and Giorgios Kamenis. Palaia Kameni lies about 0.5 kilometer southwest of Giorgios Kameni. Compare plate 9.

The slight bedding of the pumiceous material at Santorini indicates, according to Fouqué (page 293), that its ejection took place during varying phases of a single eruption, which, like the modern ones, may have lasted for some years, whereas at some of the other volcanoes, notably Vesuvius and Krakatoa, the pumiceous phase was of brief duration, measured by a few days.

Date of the explosion.—Fouqué (page 130) assigned, "with great reserve," the date of about 2000 B. C. to the paroxysmal eruption that formed the caldera. He based this on two somewhat dubious and arbitrary lines of volcanological argument, which I questioned many years ago,[28] when archæologists thought that it might be possible to determine the then unknown date of the ancient vases of Santorini from that of the explosion. The tables have now been turned, and archæology comes to the aid of volcanology in assigning an approximate date to the event which, oddly enough, does not differ widely from that of Fouqué, in whose day the archæological argument was unavailable.

In 1866 stone walls of very early, prehistoric houses were found at Acrotiri on Thera, and on Therasia, and since then others have been uncovered. These walls lay at the base of the pumiceous beds and were undoubtedly standing at the time of the great explosion.[29] The skeleton of a man who seems to have been crushed by the fall of the ash-covered roof may indicate that the beginning of the eruption was sudden. In and around the houses were found many objects of pre-Hellenic age. Of these, the only ones that interest us are the vases, which are of primitive design and pre-Mycenean—that is, before about 1500-1400 B. C. Dörpfeld,[30] on the basis of later finds near Acrotiri, dated the explosion at about 1500 B. C. According to more recent knowledge of Cycladic pottery, the date of the Thera vases is assigned "tentatively to Middle Minoan III to Late Minoan I (about 1800-1500 B. C.)," [31] which may be taken as the approximate date of the paroxysmal explosion.

THE CENTRAL ISLANDS

Slightly south of the center of the lagoon is a group of small islands (plate 10), all of which have been formed by eruptions within historic times. The names, dates, and heights in meters (in 1875) of these are as follows: Palaia Kameni,[32] 46 A. D., 98 meters; Mikra Kameni, 1570-3

[28] Washington: Amer. Jour. Archæol., vol. 9, 1894, p. 504.

[29] For descriptions of the early excavations and finds, see Fouqué, Santorin, pp. 94-131.

[30] Dörpfeld: Archäol. Anzeiger, 1901, p. 105.

[31] Renaudin: Bull. Correspondence Hellénique, vol. 46, 1922, p. 145. I am indebted to Miss Gisela M. A. Richter, of the Metropolitan Museum, New York, for this reference.

[32] The term *kameni* (καμένι = burnt) is used in modern Greek to denote a volcanic cone or site of an eruption. I adopt the form *kameni*, following Fouqué and Ktenas, instead of *kaimeni*, previously used by me.

A. D., 70 meters; Nea Kameni, 1707-11, 101 meters; Giorgios Kameni, 1866-70, 126.5 meters. The anchorage shoal, called the Banko, about one kilometer east of Mikra Kameni, probably represents the ancient Hiera, formed by the eruption of 197 B. C. Other recorded eruptions, the remains of which are now covered by the sea, are: that of 726 A. D., represented, according to Fouqué, by a small shoal between the Banko and the Skala of Phira, and that of 1650, which formed the Colombo Bank, about 6 kilometers northeast of Thera. According to Fouqué and Philippson, the supposed eruption of 1457 was merely the falling into the lagoon of part of Palaia Kameni, resulting in the present imposing eastern, vertical scarp.

It will be seen that there is no apparent periodicity in the dates of these eruptions, although a slight tendency toward diminution in the interval between them may be suspected. Is it possible that the central island group of Santorini will become almost continuously active, with occasional "eruptions," [33] like Vesuvius, Etna, and Stromboli?

The last explosion at Giorgios Kameni took place on October 15, 1870. I found it in a feebly fumarolic state in the spring of 1893, and Ktenas reports it to have been in a similar condition in 1903 and 1911. In September, 1925, a few small fumaroles, apparently unconnected with Fouqué Kameni, were feebly active on the plateau south of the cone of Giorgios.

The two May islands, between Palaia Kameni and the southwest point of Giorgios, caused by a submarine outpouring of lava on May 19, 1866, which were originally about 60 meters long, were little more than 20 meters across in 1875.[34] In the spring of 1893 they were only about 5 meters across and less than a meter above the water. In September, 1925, the western one was only a meter or so wide and less than half a meter above the water level, while the eastern one was entirely beneath the water and was marked only by a small patch of breakers. They are evidently being rapidly washed away by the waves, as has happened at the Banko and Colombo.

[33] For the latest definition of "eruption," see Perret, The Vesuvius eruption of 1906. Carnegie Publ. no. 339, 1924, p. 15.

[34] Fouqué Santorin, pp. 71, 173.

FOUQUÉ KAMENI [35]

INITIAL PHASE [36]

It would appear that the first indications of the present eruption were slight earthquakes felt at Phira on July 28 and on August 7, 8, and 9,[37] and the rise in temperature of the water about Mikra Kameni. The fact that, as stated by Ktenas and by Critikos,[38] the seismograph of the Athens Observatory recorded no earthquake centering about Santorini during this period indicates that these feeble quakes were of truly preliminary nature and therefore of limited radius of sensibility.[39] According to Critikos, no quake has been felt at Santorini or on the neighboring islands since the beginning of activity. There is no record of subsidence of the land at Nea or Mikra Kamenis, which was the most marked initial feature of the eruption of Giorgios in January, 1866; but, as the central islands were uninhabited in 1925, such may have occurred, for the very early flows of lava would soon have covered all evidence of it.

The first indication of volcanic activity was the appearance of a column of white vapor behind Mikra Kameni, seen from Phira at about 9 or 10 a. m. of August 11. Later, at about 3 or 4 p. m., the first explosion occurred, producing a high, gray, cauliflower column, accompanied by much noise and the ejection of stones, lapilli, and ash—greatly terrifying the inhabitants of Thera. This initial eruption, studied from its beginning by MM. Georgalas and Liatsakas, of Phira, was submarine and took place in the narrow strait between Nea and Mikra Kamenis, about midway between their craters (× in plate 10). An islet was soon formed, and the lava-flows, which issued continuously, soon joined Mikra to Nea Kameni and flowed north and south along the strait, their rough surfaces rising some meters above the water level and rapidly filling the whole strait. White-vapored fumaroles soon appeared near the top of the east side of the Nea Kameni cone and on the northeast flank of Giorgios. On August 23 the new dome was said to be 73.5 meters high, without a crater. The stones thrown out (and those which made up the flows) were angular blocks, not rounded "bombs." Flames were seen at

[35] Professor Ktenas (op. cit., p. 377) has suggested that the present eruptive edifice be named Fouqué Kameni, in honor of the eminent French scientist to whose classical and monumental work our knowledge of the group is largely due. I most heartily endorse and adopt Professor Ktenas' very appropriate name.

[36] For the description of the initial phases I avail myself of the notes in the Comptes Rendus cited above, in addition to information obtained by me at Phira.

[37] These dates are given by Ktenas, confirmed (in part) by my own information. Critikos mentions only two, on July 10 and 18.

[38] Critikos: C. R. Acad. Sci., vol. 181, 1925, p. 923.

[39] Cf. Montessus de Ballore, La Géologie Seismologique, Paris, 1924, pp. 226-228.

the summit of the dome from an early date, but were apparently not very abundant. Since then the volcanic activity, the succession of explosions, and violent emission of stones, lapilli, and ash have been continuous, at least until October 27, according to a note kindly sent me by Professor Ktenas.

ERUPTION OF SEPTEMBER, 1925

General statement.—A splendid general view of the central islands and of the eruption was to be had (figure 2) from the town of Phira, about 3 kilometers away to the east-northeast and many hundred meters higher, so that one could see the dome over the cone of Mikra Kameni.

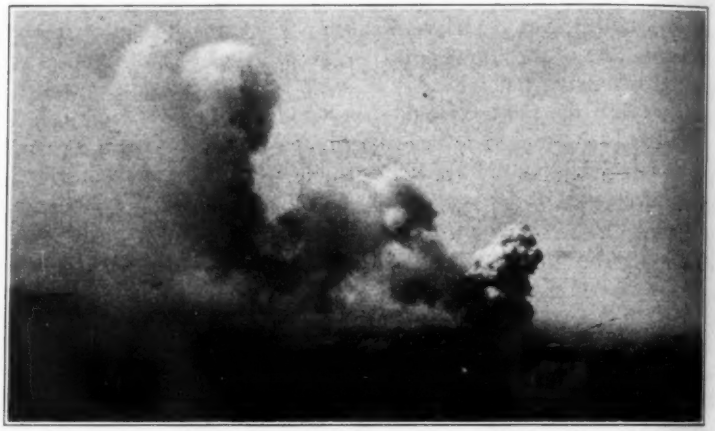


FIGURE 2.—*Fouqué Kameni from Phira*

Distant 3.5 kilometers, looking west-southwest. Mikra Kameni is in right foreground; behind it the vulcanian column from Fouqué Kameni. Note the steam at the end of the east lava-flow, to the left of Mikra Kameni, and the fumaroles on Nea Kameni above Mikra Kameni. View taken September 20.

During the day the continuously ascending column of gray "smoke" and the tremendous explosions were very impressive, their noise keeping many persons awake at night during the first few weeks. At night the spectacle became magnificent, when great bursts of incandescent blocks were hurled high in every direction from the red-hot glowing dome and rolled down the slopes of the near-by cones.

Some flames were to be seen, with the binocular, playing over the dome, but they do not seem to have been as numerous or as prominent as those during the eruption of 1866. Most of them were bluish or greenish blue; some were yellow or red. They were not visible during the

daytime, from our viewpoint, on September 19, about 500 meters distant.

The temperature of the water in the lagoon was observed by Dr. Kokkoros, as we approached the central islands in a boat. At the Skala of Phira it was 20 degrees, and gradually increased, reaching 69 degrees at the Banko and a few hundred meters from the ends of the lava-flows, near which the water appeared to be boiling. Near the north shore of the central islands the water of the lagoon was streaked with brilliant yellow and orange, due to the hydrolytic precipitation of colloidal ferric hydroxide, and this extended outward, according to the currents. In general, the lagoon water was of a jade-green color, instead of its normal deep blue. In places, near the lava-flows, and at different times, the

FIGURE 3.—*Viewpoint of September 19, on Right, looking East*

The short southwest flow to left is below. Steam rising from the east lava-flow entering the lagoon behind ridge. Cone of Giorgios in lower left corner. Phira on edge of cliffs in the center background.

waters of the lagoon emitted a rather strong odor of hydrogen sulphide. Many fish were killed by the high temperature of the water and by the poisonous gases.

The Fouqué dome.—From our boat at the end of either of the lava-flows something could be seen of the active dome, but the view was interfered with by the intervening lava-flows (10 or more meters high) and by the steam rising from the water and from fumaroles on the flows (figure 11). The showers of hot stones frustrated attempts to view the dome from Mikra Kameni, from the cone and the northern ridge of Nea Kameni, and from the north and northeast slopes of Giorgios. Finally (September 19) an excellent place of observation was found along the

ridge of the north flow of Giorgios Kameni, shown by the thick line on plate 10. This was about 500 meters distant from and almost due south of the dome (figure 3).

Seen from here, it was obvious that the center of activity had shifted notably from its initial site beneath the waters of the narrow strait to a point about 200 meters to the south, so that the dome of Fouqué Kameni now rests on the previously existing low land to the east of the Nea Kameni cone.[40] A similar shifting of the center of activity was observed at Giorgios Kameni in 1866.[41]

The fumaroles, emitting white vapor, near the top of the east slope of Nea Kameni, which had begun in August, 1925, were very active (see

FIGURE 4.—*Fouqué Dome from the South, about 500 Meters Distant*

Note flat top of dome. North steam blast rising from behind dome. Mikra Kameni on extreme right, below it the east lava-flow. East slope of Giorgios Kameni at lower left corner; beyond it east slope of Nea Kameni, with fumaroles near summit. View taken September 19.

figures 4 and 5), but those on the north slope of Giorgios Kameni were insignificant.

From the date of our arrival we had noted that the dome of Fouqué Kameni was constantly increasing in size. On September 19, from our viewpoint, 500 meters to the south, the dome could be fairly well seen in the intervals between the great explosions (figure 4). It formed a dome,

[40] The position would be approximately that of the light-colored field shown in Fouqué's plate V (1866) or back of the dark house ruin in the lower center of Fouqué's plate XV (1867). All of these house ruins, which (half submerged) were standing in 1893, are now covered by the present lavas.

[41] Fouqué: Santorin, pp. 65, 76.

circular in plan, which was estimated by me to be about 150 meters in diameter and about 50 meters high[42] above the plateau of new lava. The form of the dome was changing continually. During our stay on September 19 it had first a flat, almost horizontal, summit (figure 4); then a regular domal form (figure 5), and finally was irregular, with an apex

FIGURE 5.—*Fouqué Dome from the South*

Note domal form. White southeast steam blast near base of dome; mixed eruption above. Giorgios and Nea Kamenis as in figure 4. Two steaming ejected blocks on Nea Kameni flow below and to left of dome. View taken September 19.

of blocks accumulated at the western side and with a lower flat extension on the east. These changes were obviously caused by the continuous redistribution of the constituent loose blocks by the violent eruptions.

[42] Professor Ktenas (op. cit., p. 520) estimated the diameter at not over 100 to 120 meters and the height at about 75 meters.

The dome rested on a plateau formed by the early lava-flows and its summit, on September 19, was about on a level with that of Mikra Kameni (70 meters above the sea).

During my week's stay at Santorini MM. Ktenas and Kokkoros and I thought that the dome consisted of, or rather was covered by, a much-fissured "carapace" of solid lava, and Professor Ktenas holds to the same opinion in his latest accessible paper.[43] Later reflection and study of Fouqué's description of the eruption of Giorgios have, however, led me to believe that the dome was not covered by a more or less continuous "carapace," but that it was (and probably now is) simply a mass of loose blocks, much like the upper part of the lava-flows (see figure 10). Such was the structure of the Giorgios dome at various stages.[44] It is difficult to conceive that any relatively thin, solid domal cover could withstand the shattering effect of the tremendous vulcanian explosions. The continual and rather rapid change in form of the dome also points the same way. Other corroborative features will be mentioned later.

The fissures in the "carapace," or the crevices between the loose blocks, were brightly incandescent at night, as seen from Phira, but were not so, or at best of a dull red here and there, in the daytime, as seen from the southerly ridge on September 19. Unfortunately, we had no optical pyrometer. But some experience with platinum crucibles heated to known temperatures in the laboratory,[45] and observation of incandescent lava-flows of approximately known temperature, at Kilauea and Vesuvius, and of the ejected bombs at Stromboli, lead me to estimate that the temperature of the upper part of the interior of the Fouqué dome was about 700 degrees to 800 degrees, certainly several hundred degrees lower than the surface temperature (1,000 degrees to 1,100 degrees) of the Kilauea and other basaltic lavas. Since the melting interval of dacitic lavas is known to be considerably higher than that of basaltic lavas, it is probable that the glow came from solid masses (blocks), not molten lava, in the interior, the heat being derived presumably from liquid lava at a greater depth or from gas reactions.

The dome showed no definite crater, in the usual sense of the term. Small jets of white vapor, apparently of water, were being emitted almost continuously from all over the dome. The great vulcanian explosions took place from different places on the upper part of the dome, especially from near the summit, but not from any fixed point and often

[43] Ktenas: C. R. Acad. Sci., vol. 181, Oct. 26, 1925, p. 563.

[44] Cf. Fouqué, Santorin, pp. xv, 75, 92. Von Seebach and Schmidt, on several pages, imply much the same thing.

[45] I am indebted to Dr. G. W. Morey for demonstrations of these.

from several simultaneously. These blew out many loose blocks, many of which fell back on the dome, more or less filling the basin formed by the explosion.[46] In this absence of a definite and more or less permanent crater, Fouqué Kameni, as well as Giorgios Kameni in its earlier stages,[47] differ from such explosive vents as those of Vesuvius, Etna, Stromboli, and many others, where a well-defined and locally persistent orifice marks the point of emission. To such volcanic edifices as Giorgios, Nea, and Mikra Kamenis, which form a low dome in the early stages, covered in the later by a well-formed cone and crater, Ktenas has given the name "conodome."[48] It is to be presumed that Fouqué Kameni will eventually develop into a conodome.

Explosive activity—General statement.—Since the initial eruption of August 11, during our stay in September, and at least up to October 19,[49] volcanic activity at Fouqué has been continuous, although irregularly pulsatory in intensity and in kinds of explosion. The explosions have been confined entirely to the dome itself, including its foot, and they were (in September) of at least three kinds. It is noteworthy that Schmidt[50] describes and figures three different kinds of explosive activity at the dome of Giorgios in 1866, often simultaneous, which closely resembled those observed by us at Fouqué in 1925. In such a simultaneous occurrence of diverse modes of explosion within a very limited area of activity Fouqué Kameni resembles the crater floor of Stromboli as I saw it in August, 1914,[51] and as it has often been observed by others. The main types of explosive activity were as follows:

Steam blasts.—There arose almost continuously from the north foot of the dome a column of vapor which was generally yellow, but at times white (figure 4). This column was narrow at the base, but expanded and thinned out upward, reaching heights of 200 to 300 meters or more. A very loud hissing noise accompanied this emission, but there was little or no ejection of stones in connection with it.

A somewhat similar, but more intermittent, steam blast was to be seen on the southeast slope. About half way up the dome there issued from time to time, very suddenly, a dense and somewhat cauliflower-like burst

[46] Ktenas (C. R., p. 564) gives a sketch showing the ejections.

[47] Giorgios later developed two craters. Craters are also present on Mikra and Nea Kamenis.

[48] Ktenas: Op. cit., p. 518.

[49] Cf. Ktenaś, op. cit., p. 518. See, also, an article in the French "Messager d'Athénes" for October 26, 1925, for a copy of which I am indebted to Mr. Arthur Garrels, United States Consul General at Athens.

[50] Schmidt, Vulkanstudien, 1874, p. 192, and Tafel V, figure 3. Fouqué (Santorin, pp. 76-77) implies much the same thing, although in less detail.

[51] Washington and Day: Bull. Geol. Soc. America, vol. 26, 1915, p. 387. See, also, the bibliography by De Fiore, Bulletin Volcanologique, 1925, pp. 113-161.

of white steam, which was projected violently outward and upward at an angle of rather less than 45 degrees with the horizon (figure 5). Some noise, but very few stones, accompanied these blasts, the location of which appeared to be quite fixed. Many similar, smaller and minor outbursts of white steam were to be seen almost continually here and there over the dome.

FIGURE 6.—*Beginning of a vulcanian Explosion*

Seen from about 400 meters to the west, between Nea and Giorgios Kamenis. Dome not visible. Note the scattered ejected blocks. View taken September 16.

Vulcanian explosions.—The most violent and the most spectacular explosions were dominantly of Mercalli's vulcanian type[52]—that is, those in which the ejected blocks and lapilli are of already solidified material, not of fused or semi-liquid matter, as in Mercalli's strombolian type of

[52] Mercalli: Vulcani Attivi della Terra, Milano, 1907, p. 135.

explosion. There may have been a slight admixture of the latter, but we could not approach near enough to determine this point. These vulcanian explosions occurred generally at, sometimes slightly below, the summit of the dome, but they were not confined to any one fixed point, nor did they issue from a definite crater. There were often two or more simultaneous explosions from different points, and occasionally the dome, so to speak, "blew its whole head off."

The intervals between these vulcanian explosions were very irregular, varying from 2 or 3 to 10 or 15 (rarely) minutes; but, on the whole, there was an approach to rhythm in the general explosive activity, which was most evident during the night hours at Phira, some two miles away. I quite agree with Ktenas[53] in attributing this approximate rhythm to the accumulation of pressure of the water vapor and other gases in the highly viscous magma until the point of resistance was passed. Such rhythmical explosions have been observed at many other volcanoes,[54] during both strombolian and vulcanian activity.

Each of these vulcanian explosions consisted of a succession of great puffs of white or light to dark gray "smoke," that majestically welled up (figure 6), as at many other volcanoes, and developed into a tall, thick column of the usual "cauliflower" type (figure 7).

The rapidly successive puffs of each explosion were almost always accompanied by a markedly crescendo-diminuendo series of loud and deep-toned roars, which were apparently due, in large part, to the explosions of the encircling coronet of jets (see page 368). The timbre of these roars had very little—indeed, generally nothing—of the peculiar, semi-metallic quality that is so noticeable and characteristic of the splashing lavas at Vesuvius,[55] Stromboli, Kilauea, and other volcanoes. The absence of such metallic timbre quality may indicate that the liquid lava is not near the surface.

The noise of these roars was so deafening that at a distance of 500 meters we often had to shout into each other's ears to be heard. Many persons on Thera and Therasia were kept awake during the first month or so. The quail, which habitually use Thera as a resting spot on their migration to North Africa, had abandoned the island, possibly because of the noise or perhaps, also, because of the smoke clouds and ash.

Although most of the vulcanian explosions were so deafeningly noisy, yet some of them, even some of the largest, were practically noiseless.[56] No systematic differences were noted in the other features of the vulca-

[53] Ktenas: C. R. Acad. Sci., vol. 181, 1925, p. 564.
[54] Mercalli: Vulcani Attivi della Terra, Milano, 1907, p. 103.
[55] Cf. Mercalli, Vulcani Attivi, 1907, p. 102.
[56] I think that this is true of the eruption shown in figures 6 and 7.

nian explosions, in the form of the column or in the ejection of stones, and the silence seemed to be connected with the non-explosion of the coronetal jets to be described presently.

These cauliflower vulcanian columns reached heights varying from at least 500 to 2,000 meters or more.[57] Upward they spread out, becoming

FIGURE 7.—*The Explosion shown in Figure 6*

View was taken about one-half minute later. For typical final development see figure 2.

less dense, and the cloud drifted away to leeward at higher altitudes (figure 2).

The vulcanian columns were evidently composed mostly of water vapor, there being a barely perceptible odor of H_2S, but none of HCl,

[57] Georgalas and Liatsikas mention one that was 3,160 meters high, the accompanying stones reaching an altitude of 1,000 meters.

500 meters to leeward. The vapor was highly charged with gray, fragmental lapilli, sand, and ash, the first two falling over us continuously on the southerly ridge and in our boat, while the fine ash was distributed over various parts of Thera.

Almost all of the vulcanian eruptions of Fouqué Kameni were accompanied by the violent ejection of many blocks of solid lava. All of these were hot, but most of them were black in the daylight, only a few being dull red, although at night they appeared bright red. The tussocks of grass on the slopes of Nea Kameni and on the saddle between it and Giorgios were charred and burnt. Many of the blocks emitted white steam for some minutes after landing, even on lava that was bare of vegetation. At night, as seen from Phira, most of the incandescent blocks became dark almost immediately after falling on the slopes of the near-by cones, but a few kept up a brilliant glow for a considerable time, perhaps a minute or so. I was reminded by this of Malladra's observation of flaming bombs at Vesuvius in June, 1923.[58]

The blocks were thrown to heights of 200 to 500 meters, often much higher, and they were scattered in all directions and to varying distances. We found ejected blocks about 600 meters west of the dome, near the small harbor of Saint George; others had fallen fully as far away, behind our viewpoint of September 19, and blocks were said to have fallen at the Banko, about one kilometer east of the dome, so that this anchorage was abandoned by shipping.

The ejected blocks varied in size from that of one's fist to lengths of nearly one meter (figure 8). They were all angular, with roughly plane irregular faces, on which conchoidal fracture was well developed. Most of the blocks were very dense, highly vitreous, and of a deep brownish black; a few were slightly vesicular and of a dull black. On striking the ground the blocks broke up, the strains in the cooling glass producing further cracking. Many rebounded, forming an impact basin.[59]

I have used the term "block" rather than "bomb" to designate these ejectamenta, partly because it better applies to their angular forms and their ejection in an already solidified state, thus distinguishing them from rounded "bombs," which are ejected in a more or less fluid state,[60] none of which were found by us. No well-defined bread crust bombs

[58] Malladra: Rend. Accad. Lincei, vol. 32, 1923, p. 419.

[59] Cf. Omori, Bull. Imp. Earthquake Invest. Comm., vol. 8, 1916, p. 213.

[60] Various volcanologists, Lacroix (Santorini, Vesuvius, Pelée), Flett (Saint Vincent), Matteucci (Vesuvius), and Mercalli (Vulcani Attivi, pp. 105, 107) make a distinction similar to that adopted here. Fouqué uses always the word "bomb."

were seen, nor did any of the blocks appear to have undergone refusion,[61] although they were incandescent at night.

No electrical discharges were seen in the columns, either by day or by night. Fouqué states that electrical phenomena were wholly lacking during the earlier stages of the eruption of Giorgios, and that they occurred only during the closing phases.[62] This appears to be true of Vesuvius during several eruptions, including that of 1906, and at other volcanoes.[63] Palmieri[64] and Perret[65] connect the increased electrical phenomena with increase in the amount of ash—a plausible suggestion, but one that does not appear to apply to Santorini in 1866-70, when there seems to have been no definite or steady increase in the emission of ash toward the end.

FIGURE 8.—*Ejected Block, about 400 Meters West of Fouqué Dome*

Length, about 90 centimeters. Note the impact basin to the left of the block. View taken September 16.

The "coronet."—The third type of explosion at Fouqué Kameni was very peculiar and unusual, if not almost unique.

As studied with binoculars from Phira at night, the eastern foot of the Fouqué dome was seen to be generally surrounded by a narrow,

[61] Cf. Lacroix, L'Éruption du Vésuve, Nouv. Arch. Muséum, vol. 9, 1907, p. 47; Day and Allen, Volcanic activity of Lassen Peak, Carnegie Publ. no. 360, 1925, pp. 69-71.

[62] Fouqué: Santorin, p. 93. See, also, Schmidt, Vulkanstudien, p. 105.

[63] Mercalli: Vulcani Attivi della Terra, pp. 116-119; Lacroix, La Montagne Pelée, pp. 471-477.

[64] Palmieri: The eruption of Vesuvius in 1872, London, 1873, p. 131.

[65] Perret: The Vesuvius eruption of 1906. Carnegie Inst. Publ. no. 339, 1924, pp. 92-94.

brightly incandescent, red ring, which was very clearly an encircling crevice. At times parts of a similar outer, concentric crevice were seen here and there, not far from the inner one.

These crevices could not be made out in the daytime, at least distinctly, from our position south on September 19; but at irregular time intervals there arose from around the foot of the dome on the west and southwest sides, about where the crevice would be, a series or battery of narrow white or light gray, diminutively cauliflower jets of vapor. Through the general clouds there could be discerned the presence of a similar series behind the dome, on the east and northeast sides; these were visible from Phira in the daytime. The jets of these series always exploded simultaneously, with a crescendo-diminuendo succession of roars, the vapor rising vertically and forming a sort of crown, like upraised fingers, around the dome. These jets attained altitudes of only 50 to 100 meters or so, and they appeared to issue from points roughly equidistant from each other and not very far apart, possibly not more than 10 to 20 meters. The number visible at any one explosion was variable, from four or five to eight or ten; possibly more. I obtained no good photograph of these jets, but some slight traces may be made out in figures 4 and 5.

The emission of these jets almost always immediately preceded the great vulcanian explosions, and they were simultaneously active until they were lost sight of in the dense rolling clouds. But the vulcanian explosions were not always accompanied by a crown of jets.

I would suggest that this type of explosion be called technically by the name *coronet,* as such a series of jets of vapor arising vertically and simultaneously from a circular crevice resembles one of the insignia of the various ranks of nobility, the coronet, which consists of a band or fillet surrounding a cap, and from the edge of the fillet arise vertically the distinguishing ornaments.

The only other instance of such a mode of explosive activity that I can find in the literature is that recorded of Giorgios in April, 1866[66]—that is, at a very early stage of the eruption. A more doubtful case is that of Novarupta, near Katmai, in Alaska, which will be referred to later.

The origin of the encircling crevices and of the coronet is problematical. Fouqué does not doubt that "cette curieuse disposition" of the "fosse environant l'amas centrale" (which was 1 to 2 meters wide and from which jets of vapor issued) was the result of formidable explosions. It is difficult to grasp his exact idea, but in any case the formation of

[66] Fouqué: Santorin, p. 75. Schmidt makes no mention of this. Something similar may have marked the early stages of Nea Kameni in 1707 (Fouqué, p. 24).

such encircling crevices by tremendous (central?) explosions seems to me to be somewhat doubtful.

In my opinion, the key to the puzzle lies in the up and down (generally downward) movement of the central islands and of the neighboring lagoon floor. Such movements were very conspicuous during the eruption of Giorgios, having been, indeed, the first indication of activity, and they have been noted, and some of them measured, during the present eruption. According to this interpretation, then, the narrow crevice was caused by a differential sinking of the dome itself relatively to the lava plateau on which it stands. This sinking may well have been brought about by the pouring forth of the lava below along the two channels. The weight of the dome would have its effect, and the peculiar structure, made up of a mass of loose blocks, might also well have been a factor. In a word, the process would be the reverse of the swelling or shoving up of lava, such as produced the spine of Pelée and other such "Staukuppen" (rising domes), as Bergeat calls them.[67] So few domes of the Santorini type have been studied during their formation that our data are meager, but it is reasonable to believe that such a dome might, as a whole, be capable of slight movements that would be impossible or imperceptible in the case of ordinary, especially basaltic, cones made up largely of continuous sheets of lava, with a system of dikes, and thus rigidly bound together from center to periphery.

Novarupta[68] is a small dome,[69] made up of loose blocks of rhyolite, more silicic than the dacites of Santorini. This dome shows many circumferential and radial cracks, as is seen in the illustrations in the papers just cited and in figure 9, for which I am indebted to the kindness of Dr. Fenner. In this the encircling ring of steaming fumaroles in the "moat" is especially well shown. Griggs rather vaguely suggests that subsidence occurred in the vicinity after the formation of the dome, while Fenner is noncommital; but, as no observer was present during its formation, the evidence of Novarupta does not carry much weight, although the structure of the dome appears to be closely analogous, in general, to that of Fouqué Kameni.

The series of separate jets around the dome of Fouqué and also at

[67] Bergeat: Staukuppen, Neues Jahrb., Festband, 1907, p. 310.

[68] This name was first published by R. F. Griggs (Nat. Geog. Mag., vol. 33, 1918, p. 144). An objection to the name on etymological grounds is that "Novarupta" means, strictly, "newly broken." The name "Noverupta" would mean "newly erupted" and would hence be the more correct and more appropriate form. Compare Noveboracum, the neo-Latin name for New York.

[69] See Fenner, Jour. Geol., vol. 27, 1920, p. 588; Griggs, The Valley of Ten Thousand Smokes, Washington, 1922, pp. 280, 288, 300; Fenner, techn. paper, Nat. Geog. Soc., Katmai Series, no. 1, 1923, pp. 51-56.

Giorgios may rather reasonably be supposed to be caused by large blocks that have fallen or rolled down into the crevice, closing it here and there, the jets issuing from the open interspaces. This would readily explain their separate and consecutive location, as well as the simultaneity of their eruption. The crevice would seem to have been, along its length, in direct communication with the main vapor channel, which would account for the general sympathy of action between the coronet jets and the vulcanian explosions.

Omori[70] describes and figures a "steaming circle" in the western lava field at Sakurajima. He says that the circle is "evidently no other than a particular sort of the line of dislocation or subsidence," and he attrib-

FIGURE 9.—*View of Novarupta, near Katmai, Alaska*

From photograph taken by Fenner in 1923. Note the encircling ring of fumaroles in the "moat" and the steam jets on the dome.

utes the origin of the steam jets to sea-water, into which the lava flowed. As the circle was continuously active for at least a year and a half, and as it originated in sea-water and was not explosive, it obviously does not belong to the same category as the Fouqué coronets, although it is evidence that the circular subsidence assumed at Santorini is possible.

The lava-flows.—As has been said above, soon after the initial formation of the dome in the channel behind Mikra Kameni, submarine lava-flows issued, which soon showed above water and rapidly occupied the channel, forming what we called the north and the east flows. At the

[70] Omori: Bull. Imp. Earthquake Commission, vol. 8, 1916, p. 246, and fig. 70. See, also, Koto, Jour. Coll. Sci. Tokyo, vol. 38, 1916, p. 110, and plate ix, fig. 1.

time of my visit the north end of the channel was almost filled, a small estuary being left between the new flow and the end of the north Nea flow. Ktenas' map shows the north channel completely closed, but with a small inner residual body of water unoccupied by lava, which is by now doubtless filled up. When I left (September 20) the north flow had apparently ceased moving, but the eastern flow, which had covered and

FIGURE 10.—*End of east Lava-flow*

Note the loose, angular blocks, which are black, but appear white in the photograph because of the reflection from the smooth vitreous surfaces. View taken September 14.

completely hidden the ruins of buildings left in 1870, was steadily, although slowly, advancing out into the lagoon. This movement continued at least until toward the end of October, according to a letter sent me by Professor Ktenas and the article in the *Messager d'Athènes*. A small lava-flow also extended to the south of the dome, on the low, flat land east of the cone of Giorgios (see figure 3).

In September the north and east flows were 10 to 30 meters above sea-level, and Ktenas reports that the end of the east flow was 20 to 48 meters high in October. There would seem to have been an ascensional movement since my departure.

The upper portion of the north and east flows, that fill the canal, and the short southerly tongue, all so far as may be visible, are of the structural type usual in the upper part of the flows at Santorini, especially at Nea and Giorgios Kamenis. They are made up of loose, large and small angular blocks (figure 10), which are all highly vitreous and of which very few are even slightly vesicular and none scoriaceous. These blocks are evidently produced by the rupture of the highly viscous, almost solid, effluent lava, the great viscosity being due chiefly to the high silicity of the magma and probably also to the small content in gas, as is indicated by the absence of pumiceous or even many vesicular forms, as well as by the small amount of H_2O found by chemical analysis.[71]

Evidence of motion in the flow was furnished by the occasional tumbling over or falling down of loose blocks, as well as by the gradual extension of the flows (especially the eastern one) into the lagoon. The mechanism of this motion is to be looked for in the slowly advancing, more continuous, viscous, lower part of the flow, which is at present entirely submarine and invisible. Such a structure of the cooled lava-flow, of compact lava below and loose blocks above, may be well seen from the lagoon in many of the flows on the south and west of Giorgios, and is illustrated in some of Fouqué's plates (for example, number VIII, and possibly by figure 2, plate V, of Schmidt).

The normal Santorini type of lava-flows shows analogy with the commonly occurring and well known aa type of flow, as it is seen at Kilauea, Mauna Loa, Vesuvius, and Etna, in that the upper part of the flow is thin and is composed of a rough agglomerate covering a much thicker, compact, and continuous lower portion. On the other hand, there are some important and essential differences. The upper part of the typical aa flow is clinkery, composed of very rugose, sharp and jagged, scoriaceous blocks, which are more or less agglutinated together, whereas the upper portion of the Santorini type of flow is composed of loose, unagglutinated, angular blocks, with sharp edges and smooth faces. The thick lower portion of the aa flow is always more or less vesicular and the material is mostly highly crystalline; the lower portion of a Santorini flow is not vesicular and is highly vitreous.

Lava-flows that are much like those of Santorini are met with at the Pietre Cotte on Vulcano[72] and elsewhere on the Æolian Islands, at

[71] Dr. E. S. Shepherd is later to examine the gas content of these lavas.
[72] Pergeat: Abh. Bayerischen Akad. Wiss., vol. 20, 1899, p. 167.

Novarupta,[73] on Pantelleria,[74] at Sakurajima,[75] Asamayama,[76] and at other volcanoes. The lavas of these flows are all either rhyolitic, dacitic, trachytic, or andesitic, with a percentage of SiO_2 from about 60 to well over 70, and are all highly vitreous. The typical aa flows, on the other hand, are all basaltic, with or without leucite or nephelite, and with a percentage of SiO_2 about 50, and they are mostly highly crystalline. The differences between the two types of flow may thus be referred to the difference in silicity and other chemical characters, with consequent difference in viscosity, which controls the escape of gas and the rapidity and progress of crystallization. The partially agglutinated condition of typical aa is due to the comparative fluidity of the basaltic lava, which also largely determines the characteristically rough and jagged surfaces of the aa blocks.

Stress has been laid on the differences between the typical aa and the Santorini lavas because geologists and volcanologists almost invariably refer lava-flows to either the aa or the pahoehoe form,[77] the Block- and Fladen-laven of the Germans,[78] to the aa type being referred all kinds of flows made up of discrete blocks. This has come about because of the vast mass of descriptive literature that has been written on the flows of Vesuvius, Etna, Kilauea, Mauna Loa, and many other volcanoes, the lavas of which are essentially basaltic and hence form the Kilauea type of block lava, the original aa, and also the ropy pahoehoe, a form that does not occur in the more silicic lavas. On the other hand, there are fewer and less detailed descriptions of the equally characteristic flows of the more silicic but rarer lavas, as at Santorini, Vulcano, Sakurajima, and Pantelleria, so that their quite distinctive form is scarcely recognized in volcanological literature. Thus, such standard works as those of Geikie,[79] Mercalli,[80] Schneider,[81] von Wolff,[82] and Daly[83] make no reference to the Santorinal type of block lava, assuming or explicitly stating

[73] Fenner: Techn. paper, Nat. Geog. Soc., Katmai Series, no. 1, 1923, p. 54.

[74] Washington: Jour. Geol., vol. 22, 1914, p. 704, and fig. 3.

[75] Perret: Zeits. Vulkan., vol. 1, 1914, p. 143, and fig. 8; Sidney Powers, Zeits. Vulkan., vol. 2, 1916, p. 223, and fig. 5.

[76] Omori: Bull. Earthq. Invest. Com., vol. 6, 1912, p. 111, and fig. 57.

[77] For description of the two typical forms see Dutton, 4th Ann. Rept. U. S. Geol. Survey, 1884, p. 95; Dana, Characteristics of volcanoes, 1890, p. 9; Jaggar, Jour. Washington Acad. Sci., vol. 7, 1917, p. 277; Washington, Amer. Jour. Sci., vol. 6, 1923, p. 409.

[78] Lewis (Bull. Geol. Soc. Amer., vol. 25, 1913, p. 591) considers "pillow lavas" to be a variety of pahoehoe.

[79] Geikie: Text-book of Geology, vol. 1, 1903, p. 299.

[80] Mercalli: Vulcani attivi della terra, 1907, p. 177.

[81] Schneider: Die vulkanischen Erscheinungen der Erde, 1911, p. 87.

[82] von Wolff: Vulkanismus, vol. 1, 1914, p. 371.

[83] Daly: Igneous Rocks and their Origin, 1914, p. 290.

this to be of the Kilauean variety. Friedländer seems to be the only one to recognize clearly the difference between the two forms. After describing aa and pahoehoe, he says:[84]

"Die Oberflächenerscheinungen der stark sauren Laven lassen sich nicht gut unter diese beiden Gruppen bringen. . . . Im allgemeinen sind sie den Blocklaven ähnlicher als den Fladenlaven und entweder von scharfkantigen Bruchstücken und Blöcken oder auch von Bimmsteinkrusten bedeckt."

Also, both Perret[85] and Powers[86] remark on the difference between the characters of the Sakurajima lavas, which contain from 60 to 62 per cent of silica, and those of the ordinary aa.

FIGURE 11.—*Terminal Front of North Flow.*

Showing steam rising from the flow and from the lagoon. North flow of Nea Kameni on right, Glorgios Kameni in background. View taken September 14. See, also, figures 2 and 3.

Indeed, the causal and material differences described above are so marked that the Santorini type of flow would seem to be as deserving of a special name as aa and pahoehoe. I refrain from such a bestowal, leaving that to my Greek colleague, Professor Ktenas, if he deems it advisable.

Much of the surface of the lava-flows was emitting steam, and the lava blocks appeared to be quite hot, although they were cool enough at the farthest point of the end of the east flow to permit landing and collecting

[84] I. Friedlaender: Zeits. Vulkan., vol. 1, 1915, p. 221.
[85] Perret: Zeits. Vulkan., vol. 1, 1914, p. 143.
[86] Powers: Zeits. Vulkan., vol. 2, 1916, pp. 222-224.

(figure 10). Near the end of both flows, especially the northern, there were definite steam fumaroles on the flow.

Steam issued from the lagoon along most of the terminal fronts of both flows (figure 11). The amount was very variable, depending largely on the meteorological conditions, but the amount seldom equaled that shown in illustrations of lava-flows entering the sea at Sakurashima[87] in 1914, Stromboli[88] in 1915, and the Alika flow of Mauna Loa in 1918.[89] Nor was there any noticeable development of rows of steam spiracles, such as were visible along the fronts of these flows at Giorgios.[90] On September 14, a clear and very hot day, many tall, slender, and graceful steam whirls arose from the hot water at intervals and drifted slowly to leeward. Similar steam whirls, or "trombe," as they are called in Italian, were seen at Sakurajima[91] and at Alika.[92]

The water along the shore of Mikra Kameni was also steaming slightly in places. Indeed, the distribution and character of much of the steam emission from the lagoon near the flows and Mikra Kameni indicated the advance of a submarine continuous flow protected by a water-cooled and flexible sheath, as has been suggested by Perret for the lava-flow of Stromboli in 1915. The May Islands, in the strait between Palaia and Giorgios Kamenis, may have been caused by such a submarine flow coming from Aphroessa, as was suggested by Reiss and Stübel; but they are thought by Fouqué[93] and by Philippson[94] to be rather the product of an outflow from a submarine fissure below them.

Petrography.[95]—The lava blocks are very dense, aphanitic, coal black, of dull luster, and with a few, small, irregular vesicles. Many small (1 to 2 millimeters), mostly tabular, white feldspar phenocrysts and a few of yellowish pyroxene are present. The specific gravity of the rock is 2.477 at 18 degrees, the low value being due to the small vesicles.

In thin-section the groundmass is seen to be composed mostly of a slightly brownish glass, which is thickly crowded with a felt of extremely minute, colorless needles, producing a typical hyalopilitic texture. These needles show almost parallel extinction and are of albite-oligoclase, like

[87] B. Koto: Jour. Coll. Sci. Tokyo, vol. 38, 1916, p. 115, plate vi, fig. 3, and plate vii, fig. 1; Omori, Bull. Imp. Earthq. Comm., vol. 8, 1916, figs. 58 and 81.

[88] Perret: Am. Jour. Sci., vol. 42, 1916, p. 456, and fig. 7.

[89] Jaggar: Bull. Hawaiian Volc. Obser., vol. 7, 1919, p. 133, and figure after p. 168.

[90] Schmidt: Vulkanstudien, plates 4 and 6.

[91] Koto: Op. cit., p. 115; Perret, Zeits. Vulkan., vol. 1, 1914, p. 148, and fig. 16.

[92] Jaggar: Op. cit., p. 134.

[93] Fouqué: Santorin, p. 74.

[94] Philippson: In Hiller von Gaertringen, Thera, vol. 1, 1899, p. 68. Cf. Koto (Sakurajima), Jour. Coll. Sci. Tokyo, vol. 38, 1916, p. 53.

[95] The lavas of Fouqué have been briefly described by Lacroix and Ktenas, C. R. Acad. Sci., vol. 181, 1925, p. 893.

those of the earlier flows, as was shown optically and chemically by Fouqué and determined by me on specimens collected in 1893. With these are some excessively minute microlites of pyroxene and small grains of magnetite. Flow texture is not evident. The tabular feldspar phenocrysts are highly euhedral and comparatively few are broken. Most of them are twinned according to the Carlsbad and albite, and a few according to the pericline, laws. Measurements kindly made for me by Dr. N. L. Bowen show that most of the feldspar phenocrysts are of labradorite, having a composition of about Ab_2An_3. Many are slightly zonal, with a more albitic border. There are few inclusions of glass and pyroxene. Nearly all the pyroxene phenocrysts are of augite, as is shown by their oblique extinction, but there are some very rare phenocrysts of what may be hypersthene.

The ejected blocks are of two kinds. The most abundant are slightly brownish black, very dense, and without any vesicles. The rock is highly vitreous, with a slightly pitchy luster. The smooth and rather flat faces show fine conchoidal fracture, often wavy. The edges are sharp and many are either nearly straight or only very little curved. Some minute (0.1 to 0.2 millimeter) phenocrysts of feldspar and very few of augite are present. The specific gravity of the rock is 2.572 at 17.7 degrees, which is about that of the lavas of Giorgios as given by Fouqué. The groundmass, as seen in thin-section, is exactly like that of the lava blocks. The few and small feldspar phenocrysts are subhedral and many are broken. They are of labradorite, Ab_2An_3, as in the lava. Small phenocrysts of augite and grains of magnetite are still rarer. The less abundant type of ejected blocks is pure black, with dull luster and rough feel. These blocks are distinctly and irregularly vesicular, being almost scoriaceous in small spots. They show some very small feldspar phenocrysts. In thin-section their appearance is much like that of the other type, although megascopically they more resemble the lava blocks.

Megascopically and microscopically the material ejected by Fouqué Kameni closely resembles, and can indeed readily be matched with, various specimens of the earlier lavas of Santorini, those of the inner islands as well as those of the outer.

Two chemical analyses of the Fouqué lavas were made by my assistant, Miss Mary G. Keyes, one of a specimen from the end of the east flow and the other of the more abundant type of ejected blocks. The results are given in Table 2, with analyses of earlier lavas of Santorini. The norms are shown in Table 3.

TABLE 2.—*Analyses of Hyalodacites of Santorini*

	1	2	3	4	5	6	7	8
SiO_2	64.99	65.41	64.86	65.84	64.87	65.14	65.91	66.54
Al_2O_3	14.32	14.28	15.97	16.46	16.65	17.67	16.96	13.90
Fe_2O_3	1.30	0.75	1.88	1.39	1.46	1.59	1.36	2.55
FeO	4.01	4.08	3.89	3.80	4.21	3.33	3.47	2.94
MgO	1.12	1.00	0.95	0.91	1.42	0.95	1.13	1.60
CaO	3.94	3.79	4.02	3.50	2.88	2.96	2.42	3.98
Na_2O	6.20	5.75	4.93	4.81	5.09	5.41	4.60	4.61
K_2O	1.99	2.03	1.77	1.90	1.87	2.18	3.08	1.55
H_2O+	0.05	0.10	0.09	0.23	0.10	0.11	0.49	1.07
H_2O-	none	none	0.10	0.06	0.04	0.02	0.05	
TiO_2	2.23	2.25	0.89	0.83	1.08	1.12	1.03	0.67
P_2O_5	0.01	0.10	0.21	0.22	0.23	0.19	0.23	n. d.
MnO	0.07	0.09	0.10	0.08	n. d.	n. d.	n. d.	0.08
	100.23	99.65	99.81	100.13	99.90	100.67	100.73	99.58
Specific gravity	2.477	2.572	.....	.....	2.594	2.447	2.554	
at	18°	17.7°	.....	.....	20.2°	22°	22°	

1. East lava flow, Fouqué Kameni, August, 1925. Keyes, analyst.

2. Ejected block, Fouqué Kameni, September, 1925. Keyes, analyst. Includes S 0.02, ZrO_2, and BaO none.

3. Lava-flow, Fouqué Kameni, August, 1925. Raoult, analyst. Includes Cl 0.04, F 0.09, BaO 0.02. Lacroix and Ktenas, C. R. Acad. Sci., vol. 181, 1925, p. 895.

4. May Islands, May, 1866. Raoult, analyst. Includes Cl 0.03, F 0.07. Lacroix and Ktenas, loc. cit.

5. Block near crater, Giorgios Kameni, 1869 (?). Washington, analyst. Washington, C. R. XII Cong. Géol. Intern. (1913), 1914, p. 235.

6. Flow at summit, Palaia Kameni, 46 A. D. Washington, analyst. Washington, loc. cit.

7. Lowest flow, Therasia, prehistoric. Washington, analyst. Washington, loc. cit.

8. Bread-crust bomb, Giorgios Kameni. Luise Kichler, analyst. Tsch. Min. Pet. Mitt., vol. 32, 1913, p. 265.

TABLE 3.—*Norms of Hyalodacites of Santorini*

	1	2	3	4	5	6	7
Q	10.86	15.96	18.60	20.70	18.60	16.88	19.86
Or	11.68	11.68	10.56	11.12	11.12	12.79	18.35
Ab	52.40	48.73	41.39	40.35	42.97	45.59	38.77
An	5.28	7.23	16.40	15.57	12.23	13.90	10.01
C	....	....	....	0.92	1.73	1.33	2.35
Di	11.25	9.03	2.32	....	....	....	....
Hy	....	1.16	5.33	6.92	8.22	5.30	6.23
Mt	1.86	1.16	2.78	2.09	2.09	2.32	2.09
Il	4.26	4.41	1.67	1.52	2.13	2.13	1.98
Ap	....	0.34	0.67	0.67	0.67	0.34	0.67

1. Lava, Fouqué Kameni, August, 1925. II.(4)5.(1)2.4″.
2. Block, Fouqué Kameni, September, 1925. II″.4.2.4″.
3. Lava, Fouqué Kameni, August, 1925. (I)II.4.2(3).4.
4. Lava, May Islands, May, 1866. I(II).4.2(3).4.
5. Block, Giorgios Kameni, 1869 (?). (I)II.4.2.4.
6. Flow, Palaia Kameni, 46 A. D. I″.4″.2″.4.
7. Lowest flow, Therasia, prehistoric. I(II).4.2.4.

The two analyses closely resemble each other—so closely, indeed, that they might well be duplicate analyses of the same specimen. The marked preponderance of ferrous over ferric oxide is consonant with what appears to be the rule in the case of very vitreous rocks of various kinds, ranging from rhyolite to basalt.[96] The relation of the alkalies to lime and the composition of the normative feldspar show that, although the feldspar phenocrysts are of labradorite, the average feldspar of the groundmass would be oligoclase or albite-oligoclase, which is in harmony with the determination of the minute needles in the glass by Fouqué and by me. Similarly, the predominance of the diopside over the hypersthene molecule in the norms of numbers 1 and 2 is in line with the virtual absence of hypersthene in the rock, the pyroxene being almost wholly augite. The very considerable amount of titanium dioxide indicates that the "magnetite" grains are highly titaniferous.

The specific gravity was determined by me on hand specimens that weighed from about 240 to 840 grams. The rocks of numbers 2, 5, and 7 are very vitreous and compact and their specific gravities correspond with those given by Fouqué. The low specific gravities of numbers 1 and 6 are due to the presence of some small vesicles.

It is of interest to compare the analyses of the lavas of the latest erup-

[96] Cf. Washington, Am. Jour. Sci., vol. 50, 1920, p. 458; and vol. 6, 1923, p. 413.

tion with those of earlier ones, given in Table 1.[97] The most striking feature is the great general uniformity in chemical composition. In this respect, as also in modal and textural features, the lavas of Santorini have undergone surprisingly slight change from the period of the lowest accessible flows in the outer islands, undoubtedly many thousands of years before Christ, to the present time.

In this uniformity over a long period of time, and especially covering two distinct cycles of volcanicity,[98] Santorini is very unusual among volcanoes. At strato-volcanoes, to which type Santorini as a whole belongs, there is generally a progressive change in the composition of the lavas, although more rarely the composition remains sensibly uniform. In any case, after a paroxysmal, plinian eruption, resulting in the formation of a caldera, it seems to be generally the case that the cycle of progressive change begins anew, or, if the lavas have been previously uniform, that there is a marked change in the general composition. Examples of this behavior are numerous; of such may be cited Etna, Vesuvius, Monte Ferru, Rocca Monfina, Vico, and Pantelleria, the lavas of which are well known as regards the differences between those of two cycles. Search through the literature would doubtless reveal many more examples, although very little attention has been paid by petrologists in their descriptions of the lavas to this aspect of volcanism.

That some of the erupted magma during the earliest period of activity at Santorini was basaltic is shown by the occurrence of anorthite andesite at the base of the cliff near Acrotiri and in many of the dikes in the inner cliff of Thera, none of which penetrates the upper flows and beds of tuff, as also by the anorthitic blocks in the recent lavas, all of which are described by Fouqué. Subsequent to that period, during which only the ordinary type of Santorini lava was poured out, almost perfect uniformity has reigned, the lavas ejected after the paroxysm that formed the caldera and lagoon being identical in all essential respects with nearly all of those that preceded this event. Pelée appears to be a quite analogous case, to judge by the descriptions and analyses given by Lacroix.[99] Here there were flows of basalt during an early period, followed by successive flows of remarkably uniform composition from the earliest to the latest, these flows containing anorthitic inclusions, as at Santorini. It is noteworthy that these uniform Peléean lavas closely resemble those of

[97] The many analyses of Santorini lavas made by Pisani for Fouqué (Santorin, *passim*, and Bull. Soc. Mineral. France, vol. 25, 1902, pp. 285-314) are not considered here, as all of them are incomplete and otherwise unsatisfactory. In their general features, however, they are like those given here.

[98] Cf. Washington, C. R. XII Cong. Geol. Int., 1914, p. 229.

[99] Lacroix: La Montagne Pelée, 1904, pp. 22, 573, and 577.

Santorini chemically, although there are some mineral differences. It is possible that the andesitic volcano of Barren Island[100] is also analogous to Santorini.

A few words as to the quality of the analyses in Table 1. Although the seven analyses are closely alike as regards nearly all the constituents, the figures for Al_2O_3 are decidedly higher and those for TiO_2 lower in the analyses made by me and by Raoult than in those made by Miss Keyes. My analyses were made in 1904-5, when I had had but brief experience with the colorimetric method for titanium. Hence it may well be that my figures for TiO_2 are too low and those for Al_2O_3 too high by a corresponding amount. The excess of Al_2O_3, shown by the presence of corundum in the norm, is strongly corroborative of this, as normative excess of alumina is almost always associated with the modal presence of mica—a mineral that does not occur in the Santorini rocks. In France TiO_2 is usually determined and separated from Al_2O_3 and Fe_2O_3 by the method of prolonged boiling of an acid solution containing SO_2.[101] This method, as is well known, is very uncertain,[102] being liable to give either high or low results for TiO_2. It is, therefore, possible that Raoult's figures for TiO_2 and Al_2O_3 are erroneous in the same way as mine, and the presence of excess alumina in the norm of number 5 is indicative that this is the case. In numbers 1 and 2 TiO_2 was determined by the colorimetric method, the titanium solution having been standardized shortly before the analyses, and duplicate determinations agreed very closely. It is, therefore, to be assumed that analyses 1 and 2 best represent the composition of the lavas of 1925. I shall, therefore, interpret the analyses made by Raoult and by me in the sense indicated by them.

The predominant lavas of Santorini, such as those of Giorgios, have been called "hypersthene andesite" in most textbooks, and Rosenbusch[103] cites Santorini as the "classical locality" for this type of lava. Fouqué gives them no name in his great work, but later[104] calls them labradorite andesite or santorinite, taking into consideration only the feldspar phenocrysts, not the groundmass feldspars. Zirkel[105] reckons them among the augite andesites. Becke,[106] laying stress on the abundant groundmass feldspars, refers them to soda-rich, oligoclase hypersthene andesite, which

[100] Washington: Amer. Jour. Sci., vol. 7, 1924, pp. 446, 450.
[101] Chesneau: Principes d'Analyse Minérale, Paris, 1912, p. 307.
[102] Hillebrand: U. S. Geol. Survey, Bull. 700, 1919, p. 154; Washington, Chemical Analysis of Rocks, 1919, p. 177.
[103] Rosenbusch: Mikr. Physiogr., vol. 2, Heft 2, 1908, p. 1080; Elemente der Gesteinslehre, 3d ed., 1910, p. 379.
[104] Fouqué: Bull. Soc. Minéral. France, vol. 25, 1902, p. 285.
[105] Zirkel: Lehrbuch der Petrographie, 1894, vol. 2, p. 825.
[106] Becke: Tsch. Min. Pet. Mitth., vol. 18, 1899, p. 553.

he calls santorinite, while I,[107] following Fouqué, bestowed the name of santorinite on them, as labradorite hypersthene andesite. Iddings more recently[108] recognized the excess of quartz in the norm and referred the Santorini lavas to dacite with occult quartz.

It is evident that there is considerable confusion as to their systematic position. Assignment to labradorite andesite, based on the character of the feldspar phenocrysts, is unjustified, because the phenocrysts constitute a practically negligible proportion of the rock, and the average feldspar is approximately oligoclase. This designation follows from Rosenbusch's illogical classification of porphyritic rocks,[109] in which the character of only the phenocrysts is recognized, the mineral composition of the groundmass and the chemical composition of the rock as a whole being disregarded. Similarly, the emphasis laid by some on the hypersthene is unjustified, in view of the scarcity of this mineral and the fact that the visible pyroxene present is almost entirely augite. The norms of the best analyses also show that the occult pyroxene present in the glass base must be largely diopsidic or augitic if the rock were holocrystalline.

Simple inspection of the analyses indicates, and their norms definitely show, that all these Santorini rocks contain a very considerable excess of silica, which is occult in the glass. This modal absence of quartz has led to these lavas being called andesite, although chemically and normatively they are obviously dacite, as was recognized by Iddings, and by me in the case of the vitreous, quartz-free dacites of Pergamon.[110]

Lacroix[111] proposes the name *dacitoide* for such rocks, and he and Ktenas call the Santorini lavas pyroxene dacitoide. I prefer the term *hyalodacite* for reasons stated elsewhere,[112] and therefore designate these Santorini lavas as *pyroxene hyalodacite*, although in recent preliminary papers[113] I have spoken of them as hypersthene andesite.

A few words as to the glass of these rocks may be of interest in connection with the remarks above. Its composition is unknown because of the impossibility of calculating the mode of the rock; but a clue to some of its characters is afforded by optical means. Dr. Merwin very kindly determined the refractive index of the glass of the Fouqué block, which

[107] Jour. Geol., vol. 5, 1897, p. 368.
[108] Iddings: Igneous Rocks, 1913, vol. 2, p. 108.
[109] Cf. Cross, Jour. Geol., vol. 10, 1902, p. 471.
[110] Washington: Am. Jour. Sci., vol. 3, 1897, p. 47.
[111] Lacroix: C. R. Acad. Sci., vol. 168, 1919, p. 298.
[112] Washington: Am. Jour. Sci., vol. 50, 1920, p. 455; Boll. Soc. Geol. Ital., vol. 39, 1920, p. 153.
[113] Washington: Jour. Washington Acad. Sci., vol. 16, 1926, p. 4; Bulletin Volcanologique, vol. 3, 1926.

he found to be 1.515, and he has also found the refractive index of the glass of the similar hyalodacite of Monte Sant'Angelo, Lipari,[114] to be 1.510–1.515—that is to say, a trifle lower than that of the Santorini rock. Now, it is noteworthy that, although the two hyalodacites closely resemble each other modally and chemically, the Lipari lava shows numerous small prisms of pyroxene in the glass base which are absent or much less abundant in that of the Fouqué lava. The higher index of the Fouqué glass may, therefore, reasonably be ascribed to a higher content in occult pyroxene and may, indeed, serve as a proof that occult pyroxene exists here, if proof, other than that furnished by comparison of the mode and norm, be needed. Instances are accumulating of rocks in which much of the pyroxene belongs to the final stage of crystallization, or is occult in the glass, and this is true also of magnetite,[115] contrary to the well-known dictum of Rosenbusch. But discussion of this matter must await another occasion.

FUTURE OF THE ERUPTION

The sudden and wholly unexpected outbreak in August caused considerable consternation at Santorini, as was the case in 1866. Many persons left the islands and a large school was closed. This somewhat panicky feeling was much allayed by the reassuring statements of all the visiting geologists, both orally and in the Greek press. But there is still apprehension lest the east flow extend across the lagoon, or that some great explosion cause damage to Phira, and that much harm may be done to the vineyards in the spring by the fall of ash. The first of these events may be dismissed as an impossibility, because of the depth of water in the lagoon and for other reasons. There is also no likelihood of the occurrence of destructive *nuées ardentes,* such as happened at Pelée and Sakurajima, since the altitude of the central cones is too low. It is, however, possible that damage may be caused to the young grape buds by the ash, if this be abundant and the eruption be long enough continued.

It will have been noted that there are many points of similarity between the eruption of 1925 and the early stages of that of 1866 and

[114] Washington: Am. Jour. Sci., vol. 50, 1920, p. 453; Boll. Soc. Geol. Ital., vol. 39, 1920, p. 151.

[115] See Osann, Tsch. Min. Pet. Mitth., vol. 15, 1895, p. 451 (Apache Mts.); Washington, Jour. Geol., vol. 21, 1913, p. 705, and vol. 22, 1914, p. 21 (Pantelleria); Tsuboi, Jour. Coll. Sci. Tokyo, vol. 43, 1920, p. 116 (Oshima, Japan); Koto, Jour. Coll. Sci. Tokyo, vol. 38, 1916, pp. 170, 182 (Sakurajima); Vogt, Jour. Geol., vol. 29, 1921, pp. 629, 634 (gabbro, norite, granite); Washington, Bull. Geol. Soc. Amer., vol. 33, 1922, p. 772 (Deccan, India); Eckermann, Geol. Fören, Stockholm Forh., vol. 47, 1925, p. 307 (diabase, Sweden).

probably also of 1707. Inasmuch as both of these eruptions continued for more than three years, it seems to be probable, if a prediction be permitted, that the duration of the present eruption will also be considerable, possibly at least two or three years.

METHANA

Advantage may be taken of this opportunity to add a note on a reported eruption on the peninsula of Methana in 1922. Methana lies about 8 kilometers southwest of Ægina and, like it, is on the same volcanic belt as is Santorini. The peninsula is mostly of volcanic origin, the lavas being all andesite and dacite, the latter having a chemical composition much like that of the Santorini hyalodacite.[116]

At the northwest point is a fairly fresh-looking small cone and block-lava flow of "hornblende-hypersthene andesite" (hyalodacite), with 60 per cent of silica and 16.3 of normative quartz. This cone and flow, called the Kameni, were formed by an eruption that took place about 250 B. C. Since then, until 1922, there is no report or record of any eruption, and when I visited it in 1893 and 1894 there was no trace of volcanic activity at the Kameni, although there are hot springs elsewhere on Methana. Mercalli[117] and Sapper[118] consider it extinct.

Early in October, 1922, when I was in Rome, the papers reported that there was an eruption on Methana, presumably at the Kameni. This report was confirmed by letters from a Greek lady residing in the town of Ægina, who wrote to her sister, the wife of Director Stevens of the American Academy in Rome, that they could see the light and smoke of Methana from Ægina, about 16 kilometers away. I could not go to Methana then, but Professor Ktenas told me, when at Santorini, that he and his students were on Methana at the time of the reported eruption, and that there was no sign of activity at the Kameni or elsewhere on the peninsula, so that I did not visit it in September last. Doctors Friedlaender and Sonder[119] visited the Greek islands in the summer of 1923, in the course of which trip they landed at and examined the Kameni, of which they give a photograph. They, however, make no mention of any recent eruption, of which they would certainly have heard.

The incident is mentioned only to put the facts on record; it appears to be an example of the unreliability of reports as to volcanic eruptions.

[116] For a description of Methana and its lavas, see Washington, Jour. Geol., vol. 2, 1894, p. 789, and vol. 3, 1895, pp. 26 and 138.

[117] Mercalli: Vulcani Attivi, 1907, p. 86.

[118] Sapper: Katalog der geschichtlichen Vulkanausbrüche, Strassburg, 1917, p. 45, and Zeitschrift Vulkanologie, vol. 3, 1917, p. 70.

[119] Friedlaender und Sonder: Zeits. Vulkanol., vol. 8, 1924, p. 1, and Tafel I, figure 1.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PERMIAN VERTEBRATES FROM WEST VIRGINIA[1]

BY JOHN L. TILTON

(Presented in abstract before the Paleontological Society Dec. 30, 1925)

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INTRODUCTION

The material on which this paper is based is at present the property of the West Virginia Geological Survey and is later to become the property of the Department of Geology, West Virginia University. It is

[1] Manuscript received by the Secretary of the Society April 7, 1926.

presented for discussion with the approval of Dr. I. C. White, State Geologist. So far as known, it is the only Permian vertebrate material that has been found within the limits of the State. Because of the rarity of such material, it is thought it would prove a desirable exhibit, and it is hoped that some of the specimens may be of use in correlation of strata in West Virginia with strata in Texas and Arizona.

The writer wishes to acknowledge the photostat work of Prof. George W. Grow in preparation of the plate.

Footprints of a Stegocephalian or Reptile, Waynesburg Sandstone

LOCATION

The footprints[2] here illustrated and described came from 19½ feet below the top of the Waynesburg standstone and 13 feet above the creek

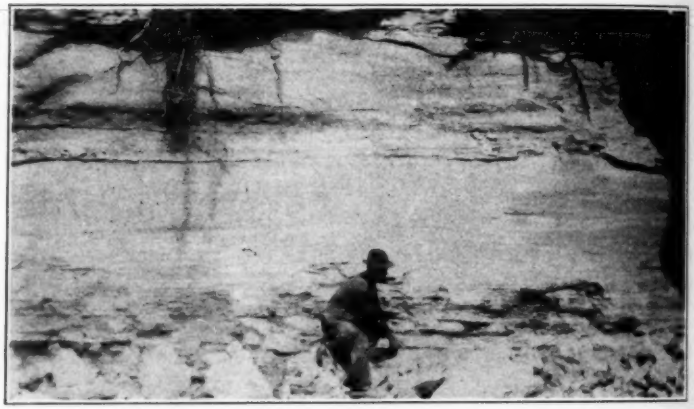

Figure 1.—*Locality where reptilian Fossils were found*

The tracks were found in the Waynesburg sandstone, at the level of the man's hand in the picture. The location is at a bluff along Island Creek at a distance of 5.7 miles northwest of West Union, West Virginia.

bed at a point 5.7 miles northwest, down Island Creek, from the nearest bridge at West Union. Where the Elm Grove limestone (0–2 feet) is absent the Waynesburg sandstone comes down next above the Cassville

[2] The tracks were discovered August 17, 1925, by Harold Riggs while removing stone in grading the road. Mr. Riggs states that the slab before it was broken had seven prints on one side and five prints on the other of the trail, and that the two lines were a foot apart, with a stride of 18 inches from a print on one side to the next similar print on the same side. The slab was broken in pieces by the workmen.

shale, the bottom of which is generally called the base of the Permian, though Permian conditions are evident far down in the Conemaugh Series.[3]

Up to the present time there has been but one small reptilian spine[4] reported from the Permian (Dunkard) of this part of the country, and parts of but one stegocephalian skeleton.[5] The specimen found east of Pittsburgh,[6] reported in 1908, came from the Conemaugh Series of the Pennsylvanian, and the tracks found in Ohio[7] are in the Monongahela, Allegheny, and Pottsville Series.

The position of these tracks and of other fossils, particularly of vertebrate fossils found within the State, is given in the following table:

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[3] It is not here intended to discuss what should be considered the base of the Permian system. That has been nicely presented by Dr. I. C. White in volume 2 and volume 2A of the West Virginia Geological Survey and summarized in the report on the geology of Braxton and Clay counties, pages 822-829. To evidence there cited may now be added the presence of Vertebraria, a plant elsewhere reported from the Permian, but near Morgantown found in the Upper Pittsburgh sandstone, and evidence from an increasing list of fossils of amphibia and reptiles.

[4] Edaphosaurus. C. R. Stauffer and C. R. Schroyer: The Dunkard Series of Ohio. Geol. Survey of Ohio, fourth series, Bull. 22, 1920, p. 147, plate 13, figs. 45, 46.

[5] John L. Tilton: Abstract, Bull. Geol. Soc. Am., vol. 36, 1925, p. 220. It is this specimen that is described in another part of the present paper.

[6] E. C. Case: Description of vertebrate fossils from the vicinity of Pittsburgh, Pennsylvania. Annals of the Carnegie Museum, vol. iv, numbers 3 and 4, Serial No. 50, 1908, pp. 234-241.

[7] In Ohio, tracks of three different kinds are reported by Prof. J. Ernest Carman as located 20 feet above the Meigs coal, No. 9, but not yet investigated. Apparently this horizon corresponds to that of the Sewickley sandstone of West Virginia, in the Monongahela Series, at about 234 feet below the horizon in which the tracks in West Virginia were located. (See report on Marshall, Tyler, and Wetzel counties, W. Va. Geol. Survey, p. 301. See also Condit's report on the Conemaugh formation, Geol. Survey of Ohio, fourth series, Bull. 17, 1918, p. 164.) Professor Carman also mentions two excellent slabs now in the Geological Museum of Ohio State University. These slabs, with numerous tracks, are from shales above the Middle Kitanning coal in the Allegheny Series.

Prof. G. F. Lamb states that a large slab of several dozen tracks of amphibians is in the geological collection of Mount Union College, Alliance, Ohio. This came from a flaggy sandstone at the top of the Pottsville, near Berlin Center, Mohoning County, Ohio.

Prof. E. C. Case has reported on *Pariesaurus* (?) *henneni* White. The report is to be found in the volume on Braxton and Clay counties, W. Va. Geol. Survey, 1917, pp. 817-822. This specimen was located in the Conemaugh Series 200 feet below the Pittsburgh coal, apparently at the same horizon as that at which Carman reports tracks in Ohio.

Certain references easy of access are of special value: Roy Lee Moodie: The Coal Measure Amphibia of North America. Carnegie Institution of Washington, No. 238, 1916. This contains an extensive bibliography. E. C. Case, S. W. Williston, and M. G. Mehl: Permo-Carboniferous vertebrates from New Mexico. Carnegie Institution, no. 181, 1913. E. C. Case: Revision of Amphibia and Pisces of the Permian of North America (with bibliography); and Discussion of fossil fishes by Louis Hussakof. Carnegie Institution, no. 146, 1911. Charles W. Gilmore: Fossil footprints from the Grand Cañon. Smith. Misc. Col., vol. 77, no. 9, publication 2832, 1926.

FORMATIONS OF THE DUNKARD SERIES (PERMIAN) OF WEST VIRGINIA

Strata.	Thickness. Feet.	Notes.
Green Division:		
Proctor sandstone	30–50	
Windy Gap limestone	5	Ostracods; Spirorbis.
Shale	30	
Windy Gap coal	Trace	
Gilmore sandstone	25	Stegocephalian intercentrum; plants.
Gilmore coal	.2	
Gilmore limestone	10	Fish teeth; ostracods; ripple-marked.
Shale	21	
Upper Rockport limestone	7	
Taylor sandstone	10	Fish teeth; ostracods.
Middle Rockport limestone	5	Ostracods; nodular.
Shale	20	
Lower Rockport limestone	8	Coprolites; ostracods, nodular, brecciated.
Shale	17	
Nineveh sandstone	20	
Nineveh coal	.5	Plants.
Nineveh limestone	10–15	Portion of skeleton of stegocephalian here described; fish teeth and scales; coprolites; insects; ostracods; plants.
Shale	46	Stumps of trees.
Burton sandstone	40	
Hostetter coal	1. 5– .5	Thins south.
Fish Creek sandstone	35	Fish scales; Pecopteris.
Fish Creek coal	1.25– .5	Thins south.
Rush Run sandstone	10–25	Ostracods; calamites.
Shale	. 5–20	
Dunkard coal and shale	. 5– 1.25	Thins south.
Jollytown sandstone	20–50	
Shale	5–10	Fish spines, scales and teeth.
Jollytown coal	. 5– 2	
Washington Division:		
Upper Washington limestone	2. 5– 9	Ostracods; brecciated; toward south becomes limy red shale.
Shale	5–10	
Hundred sandstone	30–40	
Shale	2– 5	
Hundred coal	.3	Plants; thins southwest.
Upper Marietta sandstone	30–45	
Washington A coal	. 9– 1.3	Coal disappears southwest; then limestone nodules.
Creston red shale	0–65	
Middle Washington limestone	6–12	Ostracods; limy red shale.
Lower Marietta sandstone	50	
Shale	10	
Lower Washington limestone	. 5– 5	Ostracods; fragmental.
Washington coal	. 1–10	Variable; thins south.
Washington fireclay and shale	5–10	
Washington sandstone over Little Washington coal	0–11	
Shale	10–20	Pelecypods; ostracods; insect wings; Pecopteris.

Strata.	Feet. Thickness.	Notes.
Mannington sandstone....	40–60	
Waynesburg B coal.....	1	
Shale	24	Ostracods.
Waynesburg A coal.....	.9	Plants.
Shale	15–20	Ostracods.
Waynesboro sandstone....	40–50	Footprints here described: conglomerate
Elm Grove limestone.....	0– 2	Pelecypods; gasteropods; ostracods: insects.
Cassville shale.....	0– 5	Insects; plants.
	808	

GENERAL DESCRIPTION (ILLUSTRATIONS A TO E, PLATE II)

General reference.—The tracks here illustrated were made in a thin layer of mud that covered a coarser, but still fine, micaceous sandstone. In slab A the surface is somewhat mottled, as if a slight shower had occurred after the prints were made and the water had nearly obliterated the rain-drop impressions. In the other slabs the surfaces are smoothed, as by water, with no rain-drop impressions preserved except on slab C, where a few impressions are left. The bottom of slab A is strongly ripple-marked. In slab C ripple-marks are evident in the sandstone immediately beneath the thin layer of mud on the surface. In slab D the top surface of the block is deeply marked by rounded and irregular wave impressions, with a distance of eight centimeters from crest to crest, and minor wave-marks impressed diagonally.

The impressions of the forefeet are nearly circular, about 90 millimeters in diameter, with phalangeal impressions short and broad, and deepest at tips, without distinct ungual marks. The formula is not evident, but it is clear that the third digit is the longest, and the fourth slightly longer than the second. There is no impression of a fifth digit of a front foot.

The impressions of the hind feet are elongated in the tarsal region, and the toes are only slightly less spread than the digits of the fore limb. Ungual impressions are not distinct and the toes are of the same order of length as in the forefeet. The formula is not evident, but apparently the same as that of the forefeet.

Slab A.—The first impression is that of a left forefoot with four digits, distal part deeply impressed, carpal portion less distinctly outlined. The impressions of the second and third digits are inclined, as if pressure were exerted toward the left, pushing the mud slightly that way. The first (right) impression of a digit leads directly from the left (direction), as if the radius and ulna were directed somewhat inward distally. The length of the first toe is 20 millimeters, the second 30

millimeters, the third 35 millimeters, and the fourth (left) 25 millimeters, measured from tip back to end of impression between toes. For the hind foot the length of impressions, measured in a similar manner, are (right) 22, 43, 45 and 30 millimeters (left).

Slab B.—The impressions of the three digits (2, 3, 4) of the left forefoot are preserved in much the same relation and dimensions as given for slab A. Impressions of the first and second toes of the hind foot are fairly distinct, but close to where the ungual impression of the third toe would come there are four faint impressions, as if this one toe were moved into different positions; and 25 millimeters to the left of this group of markings is another imprint, as of the ungual portion of a fourth toe, though there is no impression as of a toe extending from the heel toward this ungual impression.

Slab C.—The left margin of this impression of the right forefoot has been broken away from a point 10 millimeters back of the tip of impression of the left (first) digit for a distance of 96 millimeters, to a point directly posterior to the space between the second and third digits. Of the accompanying impression of the hind foot, impressions of three of the toes and of a portion of the tarsal margin are preserved. Of a fourth toe there is no impression.[8]

Slab D.—This slab shows a cast (obverse) of an impression of the right forefoot and of the right hind foot, preserved by sand that washed in and filled the impression left in the lower sand by the animal, and the casts are not the casts of any of the individual tracks above mentioned. The dimensions are essentially the same as the dimensions of the other tracks, but the impression of the second toe of the hind foot reaches up to the carpal area, and the impression of the third toe reaches into the carpal area of the impression of the forefoot. An impression of the fourth hind toe is absent.

Slab E.—This is a cast (obverse) of impressions of the left forefoot fairly complete, and of traces of three toes of the hind foot reaching just about to impression of the posterior portion of the forefoot. They are not the casts of the impressions of the left feet already noted.

These impressions were evidently made by an animal that held its body fairly up from the ground, whose body was short enough so that in stepping the hind foot came close to the forefoot. Had the body been

[8] Near by there are slight depressions that should not be overlooked, even though not made by the animal. Sixty-five millimeters to the left of the second toe impression is a double groove, the full width of which is 22 millimeters. Seventy millimeters from the center of the impression of the forefoot is another groove, 28 millimeters broad, but not continuous with the other groove. These grooves seem to be due to the motion of waves affecting the stratum below and not due to drag of body or tail.

long, so that two or more imprints of the forefeet would be left in the distance between fore and hind feet, one would expect distinct marks of body and tail. The uniformity of the impressions indicates leisurely advance over a ripple-marked sandy shore subjected to rain.

C. W. Gilmore, Curator of Vertebrate Paleontology at the United States National Museum, states that "the imprints shown . . . more nearly resembled tracks in the collection from Arizona than any other which I had previously seen. The shortness of the blunt, rounded digits, size, stride, and general plan of the foot all bear a certain resemblance to imprints" which he is describing[9] under the name of *Allopus*[10] (?) *arizonæ*.

Such a similarity is noteworthy, even though the tracks can not be definitely referred to Allopus, for Allopus is described as possessing five toes, while the animal that made the tracks here considered had four toes.

Portion of Skeleton of Stegocephalian, Nineveh Limestone

Location

The specimen, found by the writer in August, 1922, is in a fragment of Nineveh fresh-water limestone found outcropping by the roadside about three miles east of New Martinsville, West Virginia. A portion of two curved bones and five or six parts of other bones were exposed on the surface of the fragment and damaged by weathering.

Measurements

	Centimeters.
Total length in straight line along center of specimen	6.5
Total length along curved line or axis	7.5
Curved length of single bone best exposed, measured along center	3.7
Total width across specimen	5.0
Total width at end of specimen	4.5

Description of parts (Illustration F, Plate II)

The specimen consists of several bones in proximity to each other, arranged irregularly and loosely along a curved line or axis 7.5 centimeters long, and of a separate fragment located at a distance of 3 centimeters to one side of the others. On the right side of the curved line or axis are three strongly curved parts of bony structure. Posterior to these are parts of two other strongly curved bones. Of these parts the general shape of the first is nearly completely preserved. On the left

[9] C. W. Gilmore: Fossil footprints from the Grand Cañon. Smith. Misc. Col., vol. 77, no. 5, 1926, p. 30. The above is from a letter written with a view to quotation.

[10] Marsh: Am. Jour. Sci. (3), vol. 47, 1894, p. 83.

side are parts of three bones, robust and strongly curved, like those on the right side. The end only of the first is visible, apparently about a third of the length of the second is visible, and a large portion of the third, which is lying flat, with the free end curved across the curved central line mentioned. At the opposite end from the strongly curved, robust parts, and extending from the right side, is a thickened mass one centimeter long, at the distal end of which bones extend forward at right angles for a length of one and a half centimeters. On the opposite, or left, side of the axis is a dark fragment of bone one centimeter long and seven-tenths centimeter wide.

A portion of the margin of the part removed, three centimeters from the general mass of bones, appears scalloped, three extensions being visible on one side, with indications of smaller scallop-like border in the outermost portion. This portion is of thin bone with central opening and then ridge that thickens toward the opposite end of what is preserved. The center is constricted laterally, beyond which the portion preserved begins to widen out on the right. On the left is a rounded place in the matrix; length of space, one centimeter; width, four-tenths centimeter. The piece occupying this position was lost in an accident that occurred while photographing the specimen. The size, shape, bony structure, and fossilization of the part lying to one side of the other parts are such that it is considered a portion of the same individual to which the remaining fragments belonged.

BONY STRUCTURE

All of these parts are composed of dark material with parallel canals filled with calcite, the bones thus presenting a striated appearance where worn parallel to the canals (haversian canals) and a pitted appearance where broken across the canals. There is no evidence of concentric laminæ around openings (lacunæ). All of the parts thus appear bony, not cartilaginous.

INTERPRETATION (ILLUSTRATION F, PLATE 11)

The specimen has been submitted to Dr. E. C. Case, of Ann Arbor, Michigan, for his judgment with reference to it. He replies that he has no hesitancy in identifying it as a collection of intercentra of a rachitomous stegocephalian, and identifies portions as outlined in the accompanying photograph (F) of the specimen.

THE LIMESTONE MATRIX

The limestone in which the specimen is embedded is of the fresh-water type so common in the Permian of West Virginia. It is of a dark-gray

color, composed largely of ostracods, which are very numerous in the hand specimen, and is spotted with minute fragments of brittle carbonaceous matter. In the hand specimen were also found hollow cylindrical fragments with a combined length of 4½ millimeters and a maximum diameter of one millimeter, apparently parts of teeth. Evidently, they can not be considered to belong to the above-described specimen. At the outcrop by the roadside search was made for other bony fragments, but none were found.

Intercentrum of Stegocephalian from the Gilmore Limestone

The specimen consists of petrified bone curved into a half circle. At the broken end it is 6 millimeters wide and 2 millimeters thick. It curves uniformly to a blunt point, the distance around the outside of the curvature being 20 millimeters. The broken end reveals ducts (haversian canals) surrounded by concentric deposition.

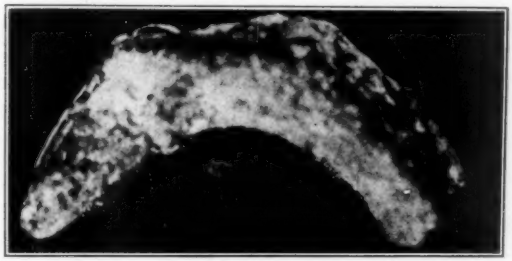


Figure 2.—*Intercentrum of Stegocephalian from the Gilmore Limestone*

The writer found the specimen by the roadside half a mile east of McKinley Central Church, Wood County. At the point where found Gilmore limestone with a clay beneath it had been dug into and the material obtained, including the specimen, spread for a roadbed. The closely compacted lime on the specimen makes it evident that the specimen had been in the Gilmore limestone and not in the shale beneath. Dr. Case recognizes it as of the Trimorachis type.

Caudal Vertebra

A single caudal vertebra was obtained from a bed of Lower Rockport limestone a few miles southeast of Rockport, Wood County.

Coprolites[11]

In the hills to the west of Rockport three or four flat pinkish masses were found in the Middle Rockport limestone. These were about two inches long, an inch wide, and a quarter of an inch thick, oval in outline, somewhat constricted near the center, one distinctly concentric in structure and all without spiral shape. These are imbedded in the limestone. The shape and color are such that they were thought to be large, somewhat flattened coprolites, the contents of which had weathered pinkish. The interior of the parts imbedded is dark in color and, where thick, shows concentric structure. No fragments of teeth or scales are found included in these coprolites.

Fish Scales

The scales are ganoid scales, rhombic, nearly square, 1.6 millimeters on a side (Palæoniscus?). One corner is slightly elongated, the others slightly rounded. Near this elongated tip or base the surface is smooth, but away from the tip the surface is crossed by nine irregular, diagonal corrugations extending in the general direction of a diagonal from this tip, and all are slightly curved, with convexity in the same direction. In some scales the corrugations are nearly straight and in some diverge from the tip or base. On some a central ridge was noted that was parallel to a side of the scale.

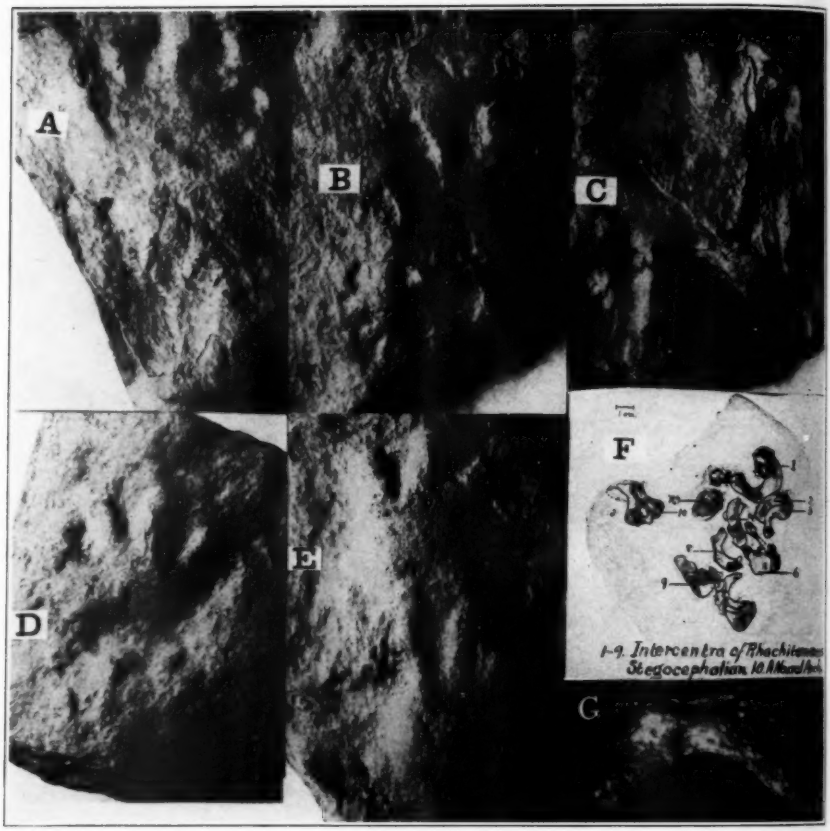
Fish Spines

Two slender fish spines were found in the Jollytown shale. One is 2.34 centimeters long, curved, longitudinally creased, and terminating in a sharp point. The other spine is 1.3 centimeters long and like the other, except that the tip is missing. The basal portion of neither is present. Another shorter and broader spine was found in the same shale that was thought to have been a marginal cephalic spine.

Fish Teeth

Fish teeth were noted in the Fish Creek shale, the Jollytown shale, and the Nineveh shale. All were minute and like those of Palæoniscus.

[11] An article by Paul H. Price on coprolites will soon appear in the Annals of the Carnegie Museum at Pittsburgh. The coprolites were found in the Round Knob (Pittsburgh shale) of the Conemaugh, at and near Morgantown, W. Va., not far from the horizon at which reptilian remains were found near Pittsburgh, as reported in vol. iv by E. C. Case



STEGOCEPHALIAN FOSSILS

The best specimen is 2 millimeters long, one-third of a millimeter in diameter at the base, and slightly curved.

DESCRIPTION OF PLATE 11

A–C. Footprints of stegocephalian or reptile, Waynesburg sandstone.

D–E. Casts (obverse) of impressions of footprints of stegocephalian or reptile, Waynesburg sandstone.

F. Portion of skeleton of a stegocephalian, Nineveh limestone.

G. Intercentrum of stegocephalian from the Gilmore limestone.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

NEW RECONSTRUCTION OF LASANIUS[1]

BY G. G. SIMPSON

(Presented in abstract before the Paleontological Society Dec. 30, 1925)

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INTRODUCTION

The earliest vertebrates of which we possess a workable knowledge occur in the Silurian, the Ordovician remains being extremely fragmentary. Of the Silurian forms none seem to be more primitive than the Anaspida, and among anaspidans the least specialized type is generally considered to be *Lasanius,* which, therefore, is of extreme interest as apparently the most primitive known fossil vertebrate. Traquair has described two species of this remarkable genus from the Downtonian of Lanarkshire, in Scotland—*Lasanius problematicus* and *L. armatus.*[3] Both are of small size, from two to fifteen centimeters in length, if reconstructions from fragments may be trusted for the larger figure. The common form, *L. problematicus,* is usually about five centimeters long.

In his earlier paper (1898) Traquair published an outline restoration of the latter species, this being the reconstruction usually met in textbooks. In 1905 he altered this slightly, making the animal abruptly larger back of the head. Professor Abel has recently published an original reconstruction based on that of Traquair.[4] These two restorations represent very logical results, in the light of previous knowledge. Still more recently, however, our knowledge of the Anaspida has been tremendously increased by the publication by Professor Kiær of a very detailed monograph on three forms found by him at Ringerike, in the southern

[1] Manuscript received by the Secretary of the Society February 10, 1926.
[3] Trans. Roy. Soc. Edinburgh, xxxix, 1898, and xl, 1905.
[4] Stämme der Wirbeltiere, fig. 30.

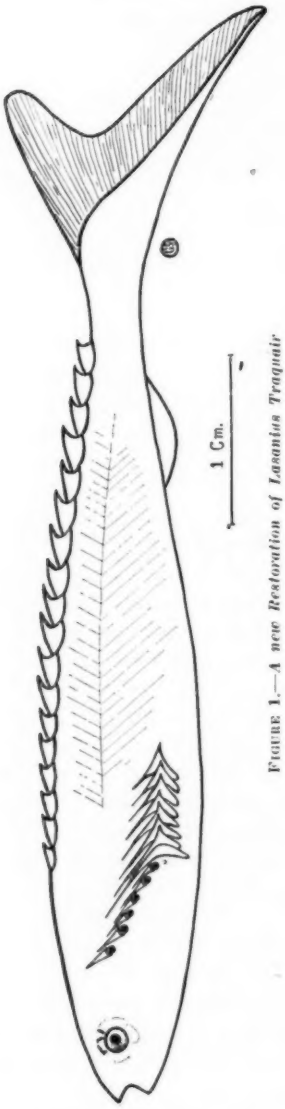

FIGURE 1.—*A new Restoration of Lasanius Traquair*

Oslo area.[5] For the first time we are in possession of really adequate information as to the appearance of forms closely allied to *Lasanius*.

In view of the special interest which attaches to the latter genus, it seems worth while to attempt a new restoration in the light of this progress. This restoration is based on the data published by Traquair, on the knowledge of related forms due to Kiær, and on a thorough first-hand study of specimens of *Lasanius* and *Birkenia* collected by W. F. Kinnear at Slot Burn, Seggholm, Ayrshire, Scotland, and presented to the Peabody Museum of Yale University by Prof. Charles Schuchert.

New Restoration

The chief differences from previous interpretations are as follows:

1. The animal is reversed, the ventral side of Traquair being taken as the dorsal. The older interpretation was based on the belief that the tail was normally heterocercal. Jaekel was of the opinion that Traquair's figures should be reversed, and the correctness of this view has been conclusively demonstrated by Kiær. The tail is not heterocercal, but hypocercal, a form unique among fishes.

2. The position of the lateral muscle plates can be faintly seen, as they can also in Professor Abel's restoration. Their position was demonstrated by Traquair in his second paper, cited above. He also showed the presence in

[5] Videnskapsselskapets Skrifter. I. Mat. Naturv. Klasse.. 1924, no. 6.

very old (large) individuals of weakly developed lateral scales, but these are either absent in smaller ones or too faint to show in a sketch restoration. They follow the myotomes in arrangement.

3. The abrupt increase in diameter back of the head, seen in Traquair's second restoration and in that of Abel, is not shown. The outline observed in the flattened fossils seems plainly due to oblique pressure, this region not being seen in true profile. In life the contour must have been evenly fusiform, as in Traquair's first restoration.

4. A slightly angulate terminal mouth is shown. Previous to Kiær's work the mouth region was unknown in the Anaspida. He has shown that in the Norwegian forms there is a very fishlike mouth. There is, however, some evidence that the mouth was more nearly round in at least *Birkenia,* and it is therefore shown rather more rounded in *Lasanius* than in Kiær's genera.

5. An unpaired anal fin has been added. This has not been surely detected in *Lasanius,* but it is present in all other anaspidans. It would hardly be distinguishable in the rusty film which, in the absence of strong dermal armor, is all that remains of this form in the rock, except for the various plates shown. There surely were no pre- or post-anal plates or spines.

6. The branchial region is quite differently interpreted from that of either Traquair or Abel. Abel considered the larger, angulate plates as gill arches. This they certainly were not, whether judged on the basis of their own structure (mentioned again below) or by comparison with the Norwegian forms, in which the homologous structures are obviously postbranchial. On the other hand, the six small plates in front of the larger ones are arranged exactly as are the circular gill or gill-pouch openings of all other anaspidans. Study of their structure as revealed by the Yale specimens shows that the lower end of each comprises a regular semicircular concavity, and to the writer no doubt seems to remain that these plates or ossicles bounded the branchial openings superiorly. They may be homologous with structures described by Kiær as follows: "In this specimen [of *Pharyngolepis*] the branchial band is seen from within, so that we obtain a view of a remarkable series of ribs that surround the openings above and at the side in a semicircle. They have thus the reverse course to that of the ribs which were described in the case of *Pterolepis.* They must be assumed to have a more deeply lying position than the latter. . . ." These inner "ribs" apparently also did occur even in *Pterolepis,* as they seem to be visible in figure 31*d* and also in Plate V of Kiær's remarkable monograph, although he does not draw attention to them in this genus. They are apparently not

modified scales, but subdermal structures. They are thus quite analogous to the gill arches of the true or higher fishes, but their homologies remain very doubtful.

7. The number of dorsal spines shown is eighteen rather than seventeen, as in Traquair's figure, or twenty-three, as in Abel's. All the specimens in which these spines can be surely counted show eighteen. They also begin a little farther forward than in the previous restorations, in accordance with one of the Yale specimens.

8. The forms of the various plates and spines differ in details from those seen in Traquair's figure or Abel's, based on it. These have been drawn from originals, in which the form is shown very clearly and in detail, from impressions both internal and external. The dorsal spines have a less quadrate base and in general are more like those of *Pterolepis* Kiær, both in form and structure, than would appear from previous reconstructions. The first of the eight larger postcranial plates is slightly different in form from the others and apparently did not bear a spine, although it had a protuberance. This would seem to be homologous with the postbranchial plate of Kiær. It shows the same tendency to longitudinal division in the upper part noticed by that authority for the next plate. The second plate is probably homologous with Kiær's pectoral plate, while the other six have disappeared in the Norwegian forms or are represented by mere vestiges. The upper arm of each of these plates is more slender and much more sharply pointed than in Traquair's restoration, and they differ much more in length. The lower portion is a little more developed. The branchial plates, or bars, are six in number, as Traquair showed, although for some reason he only shows five in his reconstruction. Their shape can be seen in the Yale material without the least doubt, when they are studied in strong oblique light with a binocular microscope, and is as shown. They differ very little among themselves. The upper end of each one is certainly posterior to the one above, rather than anterior, as in the older reconstructions. These many differences in the details of the plates would be of specific value if confirmed, but it is the conviction of the writer that they would not be seen on comparing well-preserved originals.

Primitive Characters of Lasanius

The known anaspidan genera are *Lasanius, Birkenia, Pharyngolepis, Pterolepis, Rhyncholepis,* and probably *Ctenopleuron* and *Euphanerops. Lasanius* differs from the others in the following characters:

1. There are apparently no dermal plates on the head. Scales are developed only in very old individuals and then only very feebly, and

they are regularly arranged parallel to the myotomes. All of these features are quite surely primitive.

2. There are only six branchial openings. In the other genera from eight to fifteen occur. Kiær considers this character as a specialization. If so, it is the only point in which *Lasanius* has advanced beyond its allies.

3. The postbranchial and pectoral apparatus consists of eight elements of nearly equal development. This also is primitive, there being evidence of reduction from eight to two in the other forms.

4. The anal fin is without plates, scales, or spines, and there is no preanal spine. This, too, is probably a primitive feature.

Very recently Prof. P. E. Raymond has published a brief paper on the Anaspida and the problem of the origin of the vertebrates.[6] The main thesis of this paper is that the anaspidans have a complicated and rigidly interlocking exoskeleton and no endoskeleton whatsoever. They are stated to be "simpler than *Amphioxus* in lacking the notochord, but in all other respects better prepared to cope with the world." To the present writer this conclusion seems unjustified, especially in view of what we know of *Lasanius,* the most primitive anaspidan. Kiær concludes that the structure of the Norwegian forms indicates—indeed, necessitates—the presence of a primitive endoskeleton. With him we must entirely agree. In these forms, despite the interlocking scales, the long, compressed body could hardly have been supported entirely by such numerous and freely movable elements. The mouth, also, which in at least *Pharyngolepis* and *Pterolepis* (as also *Birkenia*) is mostly surrounded by small and loose lancet scales, must have had some internal support for the attachment of muscles and maintenance of adequate rigidity. These arguments, at least as regards the presence of a notochord, seem absolutely conclusive when applied to *Lasanius.* The action of its long fusiform body, and especially of its caudal fin, which is that of a powerful swimmer, absolutely requires an axial stiffening. Its scales were very weak and certainly could not have served this purpose. Furthermore, the arrangement of the plates in this form, and also the Norwegian ones, seems definitely to depend on, and hence to have followed in point of time, that of the myotomes. These V-shaped myotomes, seen in their simplest form in *Amphioxus,* mechanically require a notochord for their functioning. The absence of such a structure in the fossils is not surprising; indeed, it could only be preserved under the most exceptional conditions. Cartilage itself, although much less perishable than

[6] American Journal of Science (5), vol. x, 1925, p. 433.

the notochord, is very rarely preserved in fossils unless calcified, and rather uncommonly even then. Furthermore, the only forms in which the preservation would give any hope of finding traces of such unsubstantial tissues, those from Norway, are so heavily scaled in all parts as to insure the obliteration or invisibility of soft internal structures.

In conjunction with its kin, *Lasanius* definitely supports the common view of the ancestral vertebrate as a naked form with a notochord. It does not bring us much closer to the problem of the invertebrate ancestor or prechordate, save that it seems somewhat to oppose any hypothesis of arthropod ancestry.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 37, PP. 403-412 JUNE 30, 1926

INTRUSIVE GRANITE OF THE ROSE DOME, WOODSON COUNTY, KANSAS[1]

BY W. H. TWENHOFEL

(Presented in abstract before the Society December 31, 1924)

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Origin of the granite and granite blocks 406
Possibilities of oil and gas production from the Rose Dome 411

INTRODUCTION

The writer discovered this granite in 1915, at which time various hypotheses were considered to account for its occurrence. As the rock lies over the prairie in scattered blocks, is extremely coarse grained, in all cases examined was found to rest on shales, and the wells, which at that time had been drilled just beyond the eastern margin of the distribution, were reported to have penetrated rocks of the normal sequence of the region, it was found difficult to relate the granite blocks to an intrusive. The results of the field and laboratory studies were published, together with all hypotheses considered, the hypothesis of the blocks having been brought to their present position by ice-action being favored.[2] Subsequently a well was drilled about a quarter of a mile south of the place of greatest abundance of granite blocks. The samples were not kept, but the driller's log showed the normal sequence. It is possible that the samples might have told a different story.[3]

In 1920 a well was drilled a little more than a half mile south of the western edge of the granite blocks. A "dacite" dike and metamorphic rocks were reported. Examination of the drill cuttings from the horizon of the reported dike indicated that only unaltered sedimentary rock had

[1] Manuscript received by the Secretary of the Society November 7, 1925.

[2] W. H. Twenhofel: Granite boulders in (?) the Pennsylvanian of Kansas. Am. Jour. Sci., vol. 43, 1917, pp. 363-380.

[3] W. H. Twenhofel: Additional data relating to the granite boulders of southeastern Kansas. Am. Jour. Sci., vol. 48, 1918, pp. 131-135.

been encountered. The problem was considered in a paper bearing the title of the "Metamorphic rocks of Woodson County, Kansas."[4] The granite has also been mentioned by Darton[5] and Powers,[6] the former relating it to the granite ridge which crosses central Kansas and the latter suggesting that the granite blocks might have been derived from a granite knob somewhere in the vicinity. The latest published statement on the occurrence is a letter of the writer published by Gould.[7]

During 1923 a well was drilled on the Rose Dome not over 300 yards northwest of the western edge of the largest pile of granite blocks and probably a considerably less distance from the occurrence of the granite beneath the surface. This well was drilled to a depth of 1,685 feet and samples were collected from the lowest 400 feet. These have been carefully studied, and the study has shown that contact metamorphic minerals are present in abundance in some of the rocks which were penetrated by the drill. The driller states that the drill cuttings contained much mica, and that some of the particles were a quarter of an inch in diameter. It is probable that the samples which were collected show less of this mineral than actually is present in the rocks.

Statements of metamorphism of the rocks over the Rose Dome have come to the writer during the past several years, and during the summer of 1924 the Rose Dome was reexamined with these statements in mind. The time could not have been more fortunately chosen, as shortly before the visit there had been considerable excavation and deepening of the ditches on the road which passes north over the dome. Contact of the granite with the inclosing shale was exposed in one place and the shales showed macroscopic alteration to the extent of the exposure, about 15 inches from the granite. The inclosing shale is black, thinly laminataed, carbonaceous, and without slaty cleavage, but at the contact with the granite the black color and decided lamination have been lost and the color has become grayish yellow. At the next nearest exposure, about 10 feet north, the shales have the normal color and lamination, seem to be unaltered, and contain fossils. Outcrops of similar shale continue for several hundred feet to the north. Samples of shale were collected for several hundred feet from the contact. These were studied in thin-section. They were found to consist of minute grains of quartz, kaolin, carbonaceous matter, and a few fragments of other minerals. Except

[4] Bull. Am. Assoc. Petroleum Geologists, vol. 6, 1921, pp. 63-74.

[5] N. H. Darton: Bull. 691, U. S. Geol. Survey, 1918, p. 5.

[6] Sidney Powers: Am. Jour. Sci., vol. 49, 1917, pp. 146-150.

[7] C. N. Gould: Crystalline rocks of the Plains. Bull. Geol. Soc. Am., vol. 34, 1923, pp. 54-55. This letter, as published, refers to the "marine distribution" of the blocks. The statement should have been written linear distribution.

for the fifteen inches adjacent to the contact, there is no evidence that the granite has had any decided influence upon these shales, although they seem to be somewhat more indurated than are other black shales in the same region. This may be due to the granite. It is thought that the splendid lamination of these shales and the fact that they are fairly hard are responsible for the statements of metamorphism. The granite at the

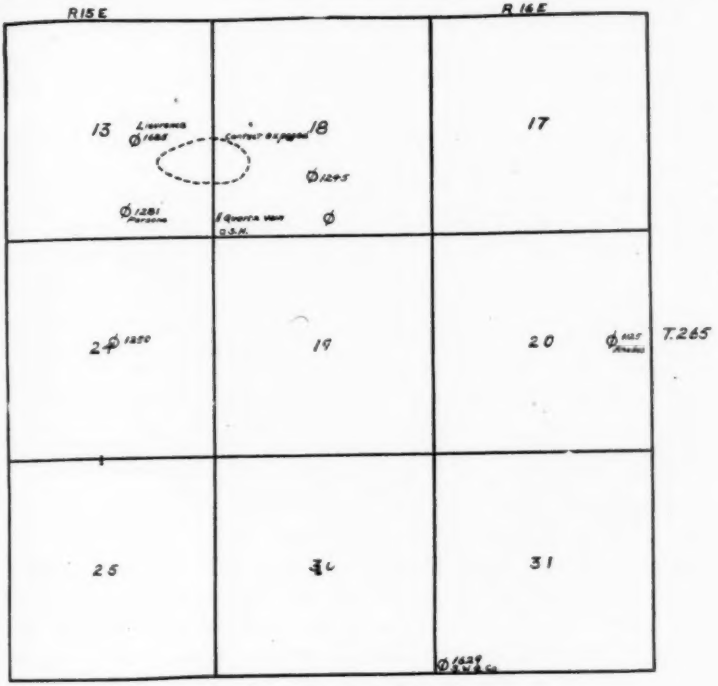

FIGURE 1.—*Map of the Rose Dome*

immediate contact is slightly finer grained for about one-half inch therefrom.

CHARACTER AND DISTRIBUTION OF THE GRANITE

The granite is a porphyry with rather large quartz and feldspar phenocrysts in a matrix of the same materials. The quartz phenocrysts range up to 10 or 12 millimeters in diameter. Some of the feldspar phenocrysts are larger, one over 20 millimeters long having been observed. In thin-section many of the quartz phenocrysts are cracked and shattered

but the particles have not been greatly moved, and in some instances the cracks have been penetrated by material of the matrix. The matrix is composed of small macroscopic crystals of quartz and feldspar in approximately equal quantities. It also contains considerable iron-stained kaolin and some greenish material which probably represents decayed iron-bearing minerals. The feldspar seems to be chiefly oligoclase, and it has been considerably altered along cleavage planes and boundaries.

The granite has the appearance of two times of development, during the earlier of which the coarser particles were formed. These later seem to have been forced apart, the quartz particles shattered to some degree, and the material forming the matrix injected between them.

The area underlain by the granite and covered to some extent by the granite blocks is thought to comprise most of the northeast quarter of the southeast quarter, section 13, township 26 south, range 15 east, and a considerable portion of the northwest quarter of the southwest quarter, section 18, township 26 south, range 16 east. This area seems to be oval in plan, although this is largely surmise, and along the east and southeast margins the only facts which have been learned have been derived from the occurrence of small particles in the soil. As there has been considerable cultivation of the land, there certainly must have been much spreading of particles beyond the limits of original occurrence. According to the known facts, it does not seem likely that the area immediately underlain by the granite greatly exceeds one hundred acres, and it may be less.

As two wells have been drilled very close to the granite blocks, one northwest of the west margin and the other south of the south margin, each going to over 1,200 feet without striking granite, it is obvious that its underground extension must be very steep on those sides and certainly on the northwest side, where it must be almost vertical. On the east margin several wells have been drilled with no granite reported. As the logs of these wells have not been seen, nor have any samples therefrom been examined, it is somewhat unsafe to draw conclusions as to the character of the downward extension on the east side.

Origin of the Granite and Granite Blocks

The theory of a glacial origin for the granite blocks is discarded, as the facts indicate that they are the surface exposures of a granite mass intrusive in the Pennsylvanian and lower strata. The conclusion of intrusive origin is based on the nature of the contact with the inclosing rocks, the presence of contact metamorphic minerals in the rocks penetrated by the well near the northwest margin, and the occurrence of pro-

nounced hydrothermal metamorphism in the Silver City area some four to five miles to the southwest.

The sedimentary rocks at the contact with the granite are shown in the photograph (figure 2), the granite being on the right and the metamorphosed shales on the left. The sedimentary rock is fine grained, has a grayish yellow color, and originally seems to have been a shale; now it has the appearance of a fine-grained quartzite. It is believed to be the baked equivalent of the black carbonaceous shales not over ten feet distant. In thin-section the major portion is composed of fine-grained

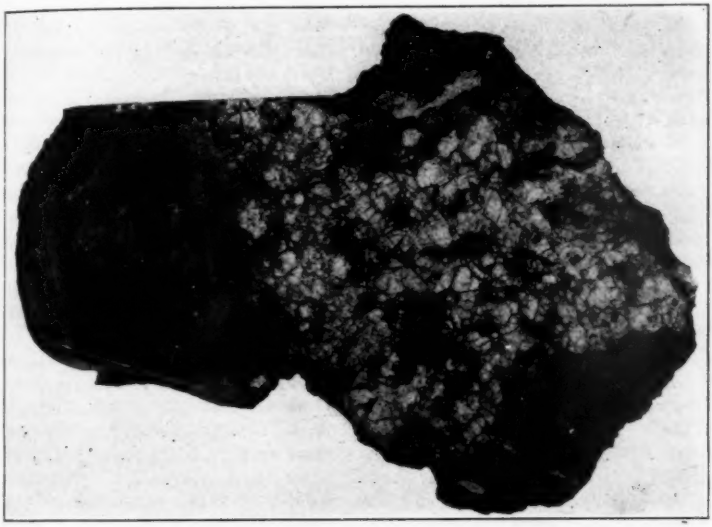

FIGURE 2.—*Photograph of a Hand Specimen of the Granite*

Showing the contact of the granite porphyry with the inclosing shale. The granite porphyry is on the right.

quartz and clay minerals, together with spots of iron oxide. Immediately adjacent to the granite there has been a little silification of the shale. Blocks of quartzitic rock similar to that exposed at the contact, together with quartzite of coarser grain, are not uncommon over the ground where the granite blocks are most abundant, and it seems obvious that they owe their origin to the same influences which rendered the silty shales at the contact quartzitic.

The well of which samples from the lower 400 feet were studied is known as the Parsons or Lieurance well Most of these samples contain

contact metamorphic minerals as diopside, pyroxene, and dark brown mica. The log of this well is given below. This log to the depth of 1,287 feet is that of the driller, as no samples were saved and nothing is known of the nature of the rock encountered other than as the driller stated. The log from the depth of 1,287 feet to the bottom has been prepared from study of the samples. It should be stated that this portion of the log is greatly different from that prepared by the driller. The log is as follows:

	Feet.		Feet.
Soil	8	White shale	682
Lime	40	Lime shells and shale	745
Shale	50	Light shale	760
Lime	60	Black shale	765
Blue shale	150	Lime	770
Lime	180	Shale	798
Blue shale	212	Lime	804
Lime	217	Shale	807
Dark shale	234	Brown lime	816
Lime	293	Dark sandy shale	820
Shale	308	Sand, lime, and shale	829
Sand	323	Brown lime	842
Dark shale	341	Brown shale	845
Hard lime	349	Hard lime	853
White shale	356	Black shale	875
Lime shells and shale	380	Lime	890
Brown lime	424	Dark shale	893
Red rock	426	Lime	900
Lime	430	Shale	905
Dark shale	435	Lime	907
Lime	460	Light shale	1,105
Black shale	468	Sand and shale	1,120
White shale	475	Light shale	1,123
Lime	510	Lime	1,129
Black shale	513	Sand and shale	1,150
Hard brown lime	550	Sandy shale	1,200
Dark blue shale	606	Dark shale	1,216
Lime	610	Black sand and shale	1,233
Light shale	660	Light shale	1,240
Lime	678	Dark shale	1,287

	Feet.
White chert with segments of crinoid columns; top of Mississippian limestone	1,298.5
White limestone and green shale, some chert	1,302
Greenish gray shale; sample contains some white limestone and chert	1,303
White limestone and chert	1,330
Greenish gray calcareous shale and pale brown shale; contains particles of the black rocks known to contain dark brown mica and pyroxene	1,340
White marbelloid limestone	1,342
White limestone, white chert, and rock resembling serpentine	1,346
White chert with white limestone. Both limestone and chert contain needle-like crystals of green diopside	1,357
Black shale containing small crystals of pyrite	1,362
White chert and gray limestone; some fragments of black chert (?)	1,369
White chert	1,375
White chert and greenish limestone	1,378
White chert and greenish limestone. Rock contains needle-like crystals of green diopside and black rock composed of dark brown mica and dark pyroxene	1,380
White chert and grayish limestone, limy shale and black rock containing dark brown mica and dark pyroxene	1,385
White chert and limestone	1,388
White limestone, calcareous blue shale, and black rock containing dark brown mica and dark pyroxene	1,392
White chert and limestone with much dark brown mica, dark pyroxene, needle-like crystals of diopside, and cubes of pyrite	1,410
White limestone and chert with much dark brown mica, dark pyroxene, and needle-like crystals of green diopside	1,414
White limestone with dark brown mica and rare crystals of green diopside	1,422
White limestone with a little pyrite, dark brown mica, and dark pyroxene	1,428
Sample consists very largely of black rock composed of dark brown mica, dark pyroxene, and some green diopside and pyrite	1,436
White limestone and some chert with much dark brown mica (5 to 10 per cent), dark pyroxene, and abundant needle-like crystals of green diopside (2 to 3 per cent). Some of the mica is in the form of superimposed hexagonal plates 2 to 3 millimeters in diameter	1,476
White chert and limestone with dark brown mica and dark pyroxene.	1,490
White limestone and chert with some dark pyroxene and much finely divided dark brown mica. There is also a white fibrous mineral resembling tremolite	1,508
White limestone containing much dark brown mica and abundant needle-like crystals of green diopside	1,508
Sample largely composed of fine-grained, dense black rock which seems to consist of dark brown mica and dark pyroxene. Some fragments of green diopside	1,572

	Feet.
White limestone and dense black rock composed of dark pyroxene and dark brown mica	1,582
White limestone and chert with some black limestone and gray shale.	1,590
Gray calcareous shale	1,592
Gray calcareous shale and gray limestone	1,595
Gray limestone with some chert. Some needle-like crystals of green diopside	1,598
Gray limestone and shale	1,600
Weathered chert; light weight and color; composed of chalcedony with some quartz. This probably marks the position of the unconformity at the base of the Mississippian	1,612
Gray limy shale	1,615
White limestone and chert with many particles of black rock composed of dark brown mica and dark pyroxene	1,618
Fine-grained quartz sandstone; may be replaced limestone	1,624
Dark shale. Brown and white mica and dark pyroxene are present.	1,627
Dark limestone rich in argillaceous and siliceous matter; contains some of the black rock composed of dark brown mica and dark pyroxene	1,631
Gray limestone and much black rock composed of dark brown mica and dark pyroxene. There is also considerable pyrite	1,639
Gray limestone and gray limy shale, with some particles of black rock like that above	1,643
Sample composed mostly of dark pyroxene and dark brown mica; some pyrite	1,675
White limestone with dark pyroxene and dark brown mica; some pyrite	1,675
White limestone with dark pyroxene and dark brown mica	1,679
Gray silt shale	1,685

In the Silver City area, some four or five miles to the southwest,[8] the sandstones of the Weston and Lawrence shales have been changed to quartzites and the Iatan limestones have been silicified, brecciated, and recemented by a matrix containing epidote and hornblende. The metamorphism is readily accounted for by the assumption of an intrusive body of igneous rock beneath the surface, and there is some difficulty in accounting for it in any other way.

The hypothesis that the granite blocks represent the surface exposures of a granite residual around which the Pennsylvanian, Mississippian, and other sediments accumulated was considered and rejected as contrary to the known facts. There was also considered the hypothesis that the granite is intrusive in the Mississippian and lower strata and a re-

[8] W. H. Twenhofel: The Silver City quartzites, a Kansas metamorphic area. Bull. Geol. Soc. Am., vol. 28, 1917, pp. 419-430.

sidual around which the Pennsylvanian strata were deposited, and this hypothesis is supported by the Pennsylvanian portions of the logs of the two near-by wells, but as no qualified person examined the samples from these wells, this support has little value. The absence of extensive metamorphism of the inclosing shales supports this hypothesis, but this also has little weight, as influences radiating from an intrusion of this dimension could not extend far therefrom. The view is opposed by the nature of the exposed contact of the granite and the inclosing shales and the higher degree of induration of these shales in comparison with similar shales in this portion of Kansas. The small quartz veins observed in the road ditch near the south margin of the granite blocks also constitute a part of the evidence supporting the view that the granite is intrusive in the Pennsylvanian. The apparent steepness of the sides of the granite also supports this view.

From the facts now known to the writer, it is concluded that the granite blocks which are strewn over the surface of the Rose Dome are the surface exposures of a granite mass that was intruded into the Pennsylvanian and lower strata. This intrusion arched the strata intruded, led to the development of contact metamorphic minerals in favorable porous and frangible rocks penetrated and baked shales for a short distance outward from the intrusion.

Granting that the granite is an intrusion, the question arises as to the date of occurrence. There are few facts on which a determination may be based. The granite blocks on the surface have been under considerable cover, otherwise it would seem that the grain must have been finer. This cover has been removed by erosion. Some of the granite also has been eroded. This would seem to require the placing of the intrusion some time during the Tertiary or even earlier.

Possibilities of Oil and Gas Production from the Rose Dome

Of the several wells which have been drilled on and adjacent to the Rose Dome, none has produced oil. It has been stated to the writer that some of the wells on the east side produced gas. If the granite has the postulated origin, it is very probable that the fixed carbon ratio in the immediately adjacent rocks has been raised to a point precluding production, and it is also probable that originally porous rocks immediately adjacent have had their porosity eliminated or at least greatly reduced. These effects, however, probably could not have extended a great distance from the intrusion, and, moreover, this reduction of porosity would have

sealed the reservoir in the vicinity of the intrusion and thus have made conditions very favorable for accumulation in any porous rocks which may occur in the sequence, provided it was possible for oil or gas to drain thereto. It is thus considered that a small oil or gas pool may some day be discovered on the flanks of the Rose Dome.

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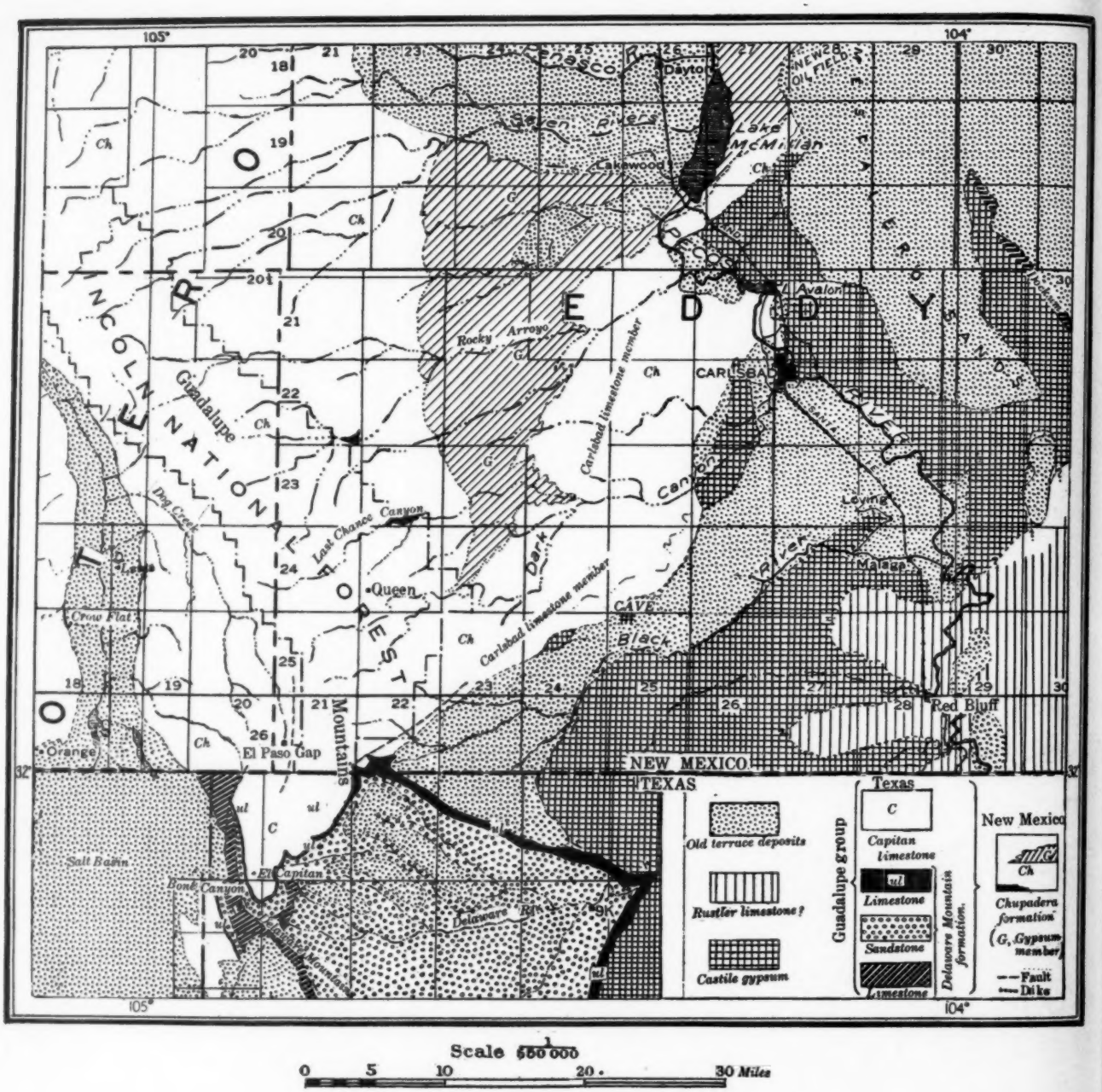

FIGURE 1.—*Reconnaissance Map of Portion of New Mexico and Texas*

Showing distribution of Permian rocks in parts of Eddy and Otero counties, New Mexico, and Culberson and Hudspeth counties, Texas. Map by N. H. Darton and J. B. Reeside, Jr.

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GUADALUPE GROUP[1]

BY N. H. DARTON AND J. B. REESIDE, JR.[2]

(*Read before the Society December 29, 1925*)

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INTRODUCTION

The rocks of the Guadalupe group, as described by Tarr,[3] Richardson,[4] Girty,[5] and others, occupy the Guadalupe Mountains, in the northern part of Culberson County, Texas. They extend northward far across New Mexico, where, on account of difference in fauna and lithology, Darton[6] has termed them the Chupadera formation. This correlation was indicated by the apparent continuity of the outcrops in the great mountain range, as previously noted by Richardson, Girty, and others. However, as there were possibilities of overlaps and separating faults, further study of the supposed continuity seemed desirable. With this

[1] Manuscript received by the Secretary of the Society April 29, 1926.
[2] Published by permission of the Director, U. S. Geological Survey.
[3] R. S. Tarr: Reconnaissance of the Guadalupe Mountains. Texas Geol. Survey Bull. No. 3, 1892, pp. 9-39.
[4] G. B. Richardson: Report of a reconnaissance in Trans-Pecos, Texas, north of the T. & P. R. R. Univ. of Texas Bull. 23 (Min. Survey Bull. 9), 1904, 119 pp., 11 pls.
[5] G. H. Girty: The Guadalupian fauna. U. S. Geol. Survey Prof. Paper 58, 1908.
[6] N. H. Darton: Geologic structure of parts of New Mexico. U. S. Geol. Survey Bull. 726, 1922, pp. 173-275.

purpose we spent part of the early summer of 1925 in an examination of the range in southern Eddy County, New Mexico, and its continuation into Texas. Fossils were collected at many points, and they have been studied by Dr. G. H. Girty as to their bearing on the correlation of the various beds and to supplement our knowledge of the extent and biology of the Guadalupian fauna.

Guadalupe Group and its Fauna

The Guadalupe Mountains in Texas consist of the capping of Capitan limestone, a light-colored massive rock about 1,800 feet thick, and the Delaware Mountain formation, of which about 2,300 feet are exposed, the base covered to an unknown amount by fill of adjoining valleys. The lowest beds exposed at the south end of the range are about 200 feet of dark limestone, above which are about 2,000 feet of sandstone, and at the top, underlying the Capitan limestone conformably, is a limestone member, about 100 feet thick, which in most places to the north is of dark color. These two formations carry the rich and very distinct Guadalupian (Permian) fauna which Girty has suggested may possibly be younger than any other Permian strata deposited under similar conditions in the United States.

The vertical distribution of the Guadalupian faunas in the Texas section is indicated in parallel columns in the table in Girty's memoir, which is too long to be repeated here. Many of the species have considerable range, but some of them appear to be more or less restricted, and the various formations and their members carry certain species and groups that are believed to be diagnostic of various horizons. A few special features of this sort relating to the faunas of the lower and upper dark limestone members are quoted in the following lists:

The following are of the Delaware fauna, and which Girty found restricted to the upper dark limestone at the south end of Guadalupe Mountains:

Cystothalmia nodulifera
Lindstræmia cylindrica
Archæocidaris cratis?
Domopora? constricta
Domopora? vittata
Stenopora granulosa
Fenestella hilli
Fenestella guadalupensis et al.
Polypora mexicana?
Chonetes permianus
Productus popei and var. *opimus*
Productus limbatus
Aulosteges guadalupensis
Pugnax bisulcata and var.
Pugnax pinguis
Spirifer mexicanus var.
Spirifer sulcifer
Spiriferina laxa
Spiriferina hilli var.
Spiriferina welleri var.
Aviculipecten guadalupensis
Euomphalus sulcifer var.

GUADALUPE POINT

Guadalupe Point is at the south end of Guadalupe Mountains, Culberson County, Texas. The view is from the east. Capitan limestone capping Delaware Mountain formation. Photograph by R. T. Hill.

Some of these species may be found to have wider range when additional collecting is done. The following were obtained not only in the upper dark limestone member, but also at other horizons:

Fusulina elongata
Spirillina aff. *S. plana*
Steinmannia americana
Lindstræmia permiana var.
Cladopora spinulata
Domopora? terminalis
D. oscellata
Fistulipora grandis var. *guadalupensis*
Leioclima shumardi
Fenestella spinulosa
Acanthocladia guadalupensis
Crania sp.
Derbya sp.
Chonetes hillanus
C. subliratus
Productus semircticulatus var.
P. occidentalis
Richthofenia permiana
Pugnax? bisulcata var.
Rhynchonella? indentata
Diclasma spatulatum
D. guadalupensis
Spirifer mexicanus
Spiriferina billingsi
Hustedia meekana and var.
Myalina? squamosa
Anisopyge perannulata

Fusulina elongata, which is abundant in part of the upper dark limestone member, also occurs in the Capitan limestone, as well as in the medial portion of the underlying sandstones.

The species which were found only in the basal dark limestone are as follows:

Anthracosycon ficus var.
Virgula neptunia
Stenopora granulosa?
Meekella attenuata
Meekella multilirata
Productus latidorsatus var.
Aulosteges sp. (2)
Pugnax nitida
Composita mexicana var.
Edmondia? bellula
Yoldia sp.
Parallelodon multistriatus
Pleurotomaria texana
Pleurotomaria? planulata
Loxonema? inconspicuum
Foordoceras schumardianum var.
Peritrochia crebus
Agathoceras texanum
Bairdia aff. *B. plebia*

The species that occur in higher strata, as well as in the basal dark limestone, are *Pugnax bidentata, P. osagensis, Hustedia meekana, Spirifer b* (like *triplicatus*), *Euomphalus sulcifer, Zygopleura swallowiana, Paraceltites elegans, Richthofenia permiana,* and *Anisopyge perannulata,* the two latter having been obtained at all horizons in the Guadalupian group.

Principal Fossils from upper Limestone Member of the Delaware Mountain Formation at Pine Spring, near El Capitan Peak, Culberson County, Texas

(Collected by J. B. Reeside, Jr.; determined by G. H. Girty)

Fusulina elongata
Lindstræmia permiana
Cladopora spinulata
Cladopora tubulata
Echinocrinus sp.
Carnocystis richardsoni
Domopora terminalis
Domopora ocellata
Fistulipora grandis var. *guadalupensis*
Fenestella guadalupensis
Polypora mexicana?
Acanthocladia guadalupensis
Goniocladia americana
Chonetes permianus
Chonetes hillanus
Chonetes subliratus
Productus sp. d.
Pustula pileola
Aulosteges n. sp.
Richthofenia permiana
Pugnax bisulcata var. *seminuloides.*
Pugnax bisulcata var. *gratiosa*
Pugnoides swallowianus
Pugnoides bidentatus?
Dielasma sp.
Spirifer mexicanus
Spirifer mexicanus var.
Spiriferella arctica var.
Spiriferina billingsi
Spiriferina laxa
Spiriferina hilli var. *polypleurus*
Composita emarginata?
Hustedia meekana
Hustedia meekana var. *trigonalis*
Hustedia papillata
Hustedia bipartita?
Schizostoma sulcifer
Schizostoma sulcifer var. *angulatum*
Orthoceras sp.
Nautilus sev. sp.
Gastrioceras sp.
Goniatites sp.
Anisopyge perannulata

This list includes many of the species found by Girty in 1901 and a few additional ones, mainly numerous gastropods and cephalopods. Observations and collections by Richardson[7] in 1909 and an extensive reconnaissance of the entire region for the geologic map of New Mexico have shown that the apparent northern extension of the formations of the Guadalupe group contains an entirely distinct fauna with few, if any, of the same fossils. It seems certain that this change must be ascribed to different conditions of deposition, possibly the presence in the waters of increased amounts of saline constituents inimical to the Guadalupian mollusca. In this connection Girty[8] makes the following comment:

"It is apparent that the Guadalupian fauna in a characteristic form is not indicated by our collection in the northern extension of the Guadalupian rocks. all the variety, all the peculiar species, which give color to it being absent. Our collections, especially from the higher horizons, are unfortunately meager and may give a perverted view of the fauna as it really occurs, but the evidence is such as to demand a consideration, if not an adoption, of the hy-

[7] G. B. Richardson: Stratigraphy of the Upper Carboniferous in west Texas and southwest New Mexico. Am. Jour. Sci., vol. 29, 1910, pp. 325-337.

[8] G. H. Girty: The Guadalupian fauna and new stratigraphic evidence. Annals N.Y. Acad. Sci., vol. 19, 1909, p. 141.

pothesis that the facies of the Guadalupian fauna is a regional matter denoting not time relations, but geographic relations."

FIELD-WORK

With this problem in mind, field-work was begun in the type locality near El Capitan, the highest peak of the Guadalupe Mountains in Texas, and the Capitan limestone and Delaware Mountain formation were traced

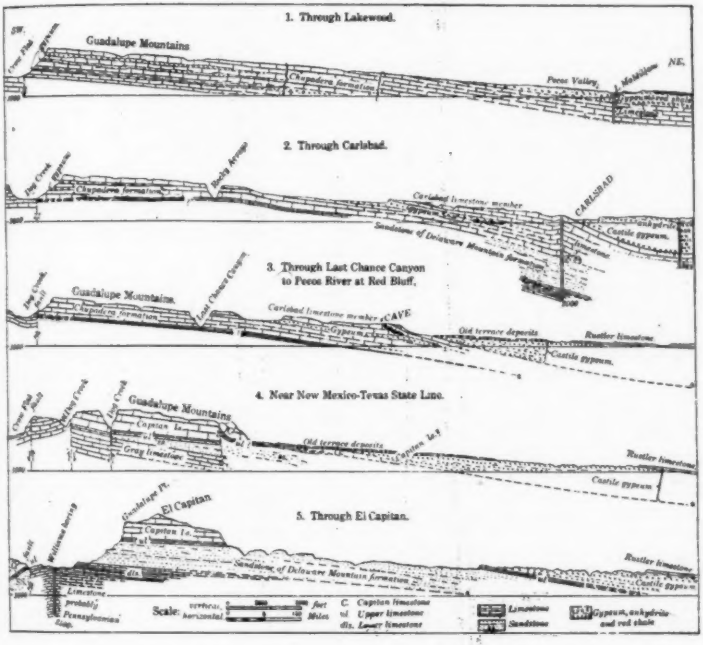


FIGURE 2.—*Sections across Guadalupe Mountains to Pecos Valley*

northward into New Mexico, along the top and both slopes of the mountains, to ascertain their relations to the Chupadera formation. Large collections of fossils were made (excepting at the type Capitan locality of Girty) with the purpose of adding to our knowledge of the distribution of the Guadalupian fauna, and especially to obtain supplementary material from the limestone members at the base and at the top of the Delaware Mountain formation in both States.

The principal relations determined by our recent observations are shown in the map, figure 1, and the groups of sections in figures 2, 3,

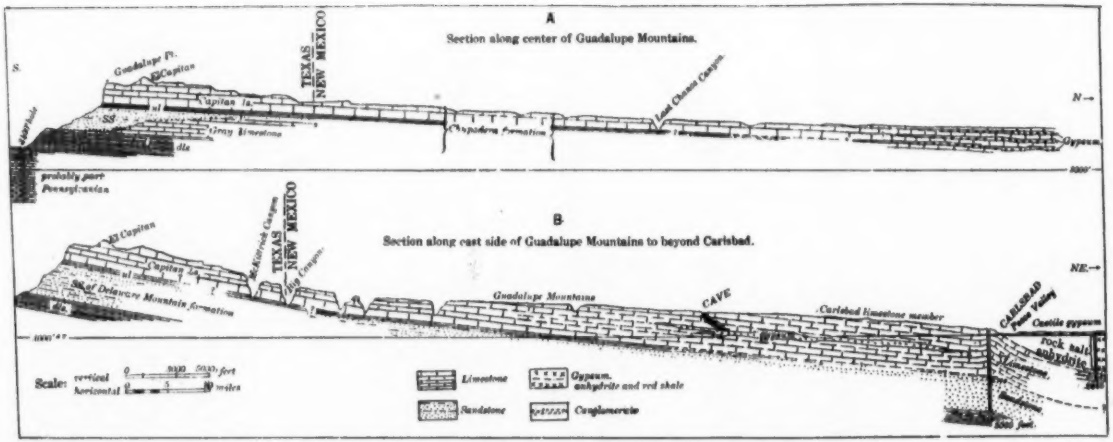


FIGURE 3.—*Sections along Guadalupe Mountains and Part of the lower Pecos Valley*

and 4. The map and sections, figures 2 and 3, also show the relations of the Castile gypsum and Rustler limestone which were not studied in detail. The sections in figure 4 show the variations from south to north.

Gradation into Chupadera Formation

The change in character from pure limestones of the Capitan and Delaware Mountain formations to the greenish-gray earthy limestones of the Chupadera formation is clearly exhibited along the central part and western slope of the mountains. On the west side, in townships 23 to 25 south, the development of gypsum deposits and red beds among these limestone beds is plainly visible. It is in this region that the lower strata of the Capitan limestone and the thick dark and gray limestones of the lower part of the Delaware Mountain formation grade laterally into lower and medial members of the Chupadera formation and Guadalupe fauna gives place to Manzano fauna.

Medial Gypsum Member

Northward from township 24 these lower strata are overlain by a succession of gypsum and red gypsiferous deposits which thickens rapidly to about 600 feet. As shown on the map and in section 1, this gypsum member underlies the Pecos Valley in a wide area in central and northern Eddy County, and it extends far northward, probably to the Roswell-Acme region. To the southward some of the gypsum merges laterally into overlying limestone and sandstone, but most of it thins, and it disappears in township 24, just east of Queen, beyond which, however, the horizon may possibly be marked by a thin bed of reddish sandstone in the middle of the Capitan limestone, which extends into Texas.

Carlsbad Limestone Member[9]

The next higher member is a massive limestone, 600 to 800 feet thick, for which the term Carlsbad limestone member of Chupadera formation is proposed. It constitutes the higher part of the mountains at El Capitan. This member extends northeastward for 40 miles with great prominence as a high ridge west of Black River Valley, and north of Carlsbad it is trenched by the Pecos River, where it outcrops in extensive ledges. Farther northeastward, however, it thins and gives place to red beds, which pass under the "Mescalero Sands" in townships 18 and 19; still farther northeast it passes under the oblique overlap of the Dockum group (Upper Triassic).

[9] Defined more fully in forthcoming report by O. E. Meinzer, B. C. Renick, and Kirk Bryan, which will be published as a Water Supply Paper of the U. S. Geological Survey.

Carlsbad Borings

Two deep wells near Carlsbad show that to the eastward the Carlsbad limestone member lies on the lower limestone without intervening gypsum, just as it does in the El Capitan region (see sections 2 and 3, figure 2, and section B, figure 3). One boring, completed early in 1926, penetrated 2,710 feet of these two limestones and an additional 2,220 feet of gray sandstone, which doubtless is the northeastern extension of the sandstone of the Delaware Mountain formation, with about the same thickness as in the El Capitan region. Limestones, mostly dark, extending from 4,930 to 5,800 feet, doubtless represent the lower member of that formation, but possibly they are in part Pennsylvanian.

Castile Gypsum

In southern Eddy County the Carlsbad limestone member of the Chupadera formation dips beneath the Castile gypsum, which in a boring 8 miles east of Carlsbad is about 2,500 feet thick (see section 2, figure 2, and section B, figure 3) and nearly 1,900 feet thick in the Flood boring in Texas, 40 miles west of Pecos. From Carlsbad to the Texas line this gypsum is mostly covered by valley deposits of sand, conglomerate, and breccia which extend along the foot of the mountains, as shown in sections 3 and 4, figure 2, and the map, figure 1, but the superposition on the limestone is well exposed at intervals, notably in the center of township 25 south, range 24 east.

Thinning of the Capitan Limestone to the Southeast

In the northern part of Texas, however, the Capitan limestone thins out very rapidly to the eastward and finally, in longitude 104° 30′, in the northeastern part of Culberson County, the Castile gypsum lies *directly on dark limestone,* which has been regarded as the top member of the Delaware Mountain formation. This thinning out of Capitan limestone to the southeastward must take place in a short distance and mostly in the southeastern part of township 26 south, range 22 east, where, however, its relations are hidden by the Quaternary sands and conglomerates above mentioned. It has been suggested that the Capitan limestone merges into the Castile gypsum, but this is precluded by the fact that the superposition of the gypsum is plainly exhibited farther north, in Eddy County, as shown in the cross-sections (figures 2 and 3) and in the deep borings. Block or overthrust faulting are out of the question. The fauna of the black limestone in the mouth of Big Canyon, in the southwestern part of township 26 south, range 22 west, suggests

SOUTH END OF GUADALUPE MOUNTAIN

[illegible] south [illegible] New Mexico. Guadalupe Point in foreground to right and El Capitan to left. Bone Spring

FIGURE 1.—LOWER LIMESTONE MEMBER OF DELAWARE MOUNTAIN FORMATION

The view is looking north, just north of Williams Ranch, Culberson County, Texas. Cliffs of Capitan limestone to right, surmounting long slope of sandstone.

FIGURE 2.—LOCAL UNCONFORMITY IN LOWER LIMESTONE MEMBER OF DELAWARE MOUNTAIN FORMATION, BONE CANYON, CULBERSON COUNTY, TEXAS

Time hiatus probably very slight. The cliff in middle is about 60 feet high.

that part of the Capitan beds may change into dark, slabby limestone of the same general character as the member mentioned above.

Bone Canyon Overlap

The stratigraphic relations of the Delaware Mountain strata are revealed on the west slope of the range, in the northern part of Culberson County, notably by interesting outcrops in and near Bone Canyon, some features of which have been noted by Baker.[10] At this place we observed a coarse conglomerate, made up largely of light-colored limestone (see plate 14, 2), at the base of the sandstone member of the Delaware Mountain formation, and also the rapid thinning of this sandstone member to the northward. In Bone Canyon the conglomerate lies on the black, lower limestone member, of which nearly 900 feet are exposed, while in the next canyon, about a mile (as shown in plate 13, top half) north, we found the deeply eroded edge of an overlying gray limestone member, 300 feet or more thick, which evidently was the source of the coarse material in the conglomerate exposed in Bone Canyon. This conglomerate is local and does not represent any great time hiatus, for Guadalupian fossils occur in the underlying limestones both gray and black. The following were determined by G. H. Girty:

Fossils from gray Limestone of lower Member of the Delaware Mountain, one Mile North of Bone Canyon, Texas

Lophophyllum n. sp.
Septopora sp.
Acanthocladia guadalupensis
Fistulipora sp.
Rhipidomella n. sp.
Enteletes sp. c.
Enteletes sp. d.
Meekella attenuata
Chonetes hillanus?
Productus guadalupensis var. comancheanus
Productus sp. a
Pustula subhorrida var. *rugatula?*
Aulosteges guadalupensis
Aulosteges magnicostatus
Richthofenia permiana?
Leptodus americanus
Composita? sp.
Hustedia meekana
Platyceras n. sp.

Fossils in black Limestone of lower Member of Delaware Mountain Formation, in Bone Canyon, Texas

Lophophyllum sp.
Cladochonus sp.
Chonetes permianus
Productus aff. *undatus*
Camarophoria n. sp.
Pugnoides? sp.
Martinia n. sp.
Martinia sp.
Nautilus sp.

[10] C. L. Baker: Contributions to stratigraphy of eastern New Mexico. Am. Jour. Sci., 4th ser., vol. 49, 1920, pp. 112-114.

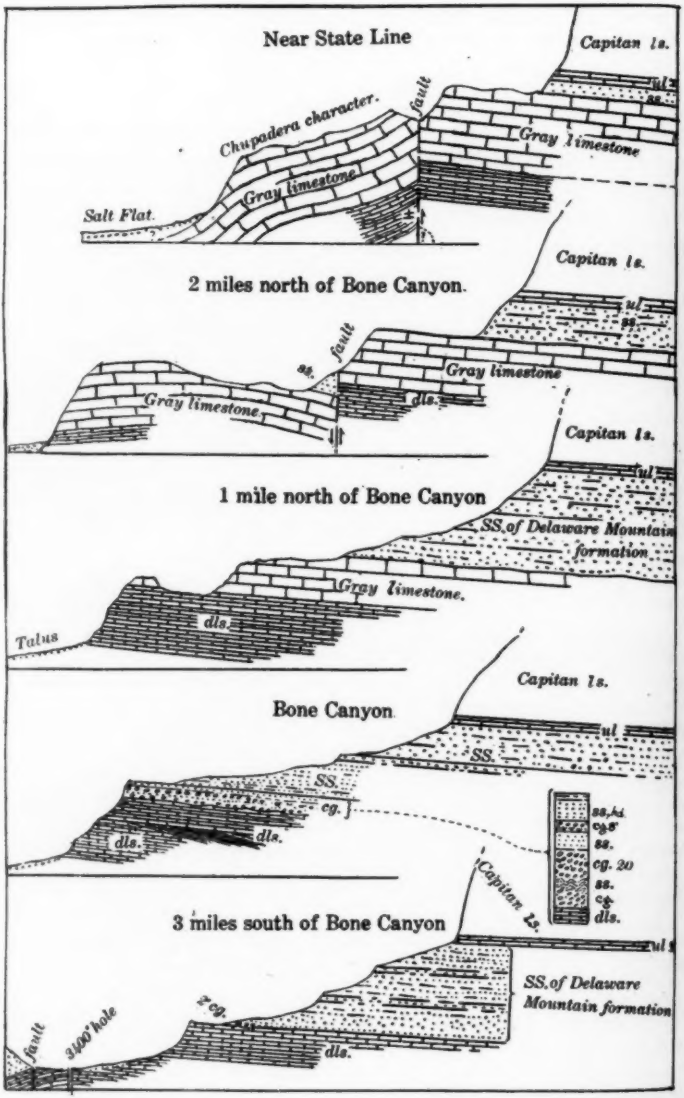
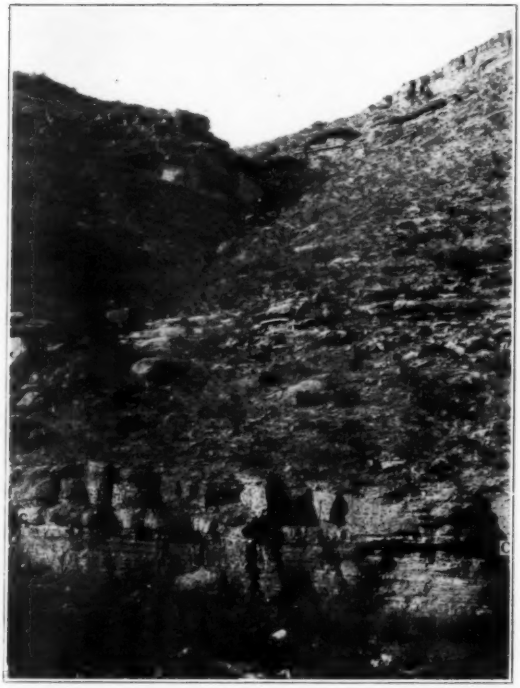


FIGURE 4.—*Sketch Sections along the West Front of the Guadalupe Mountains from near Guadalupe Point to beyond the New Mexico State Line*

CONGLOMERATE IN LOWER PART OF SANDSTONE MEMBER OF DELAWARE MOUNTAIN FORMATION IN BONE CANYON, CULBERSON COUNTY, TEXAS

Time hiatus probably slight.



FOSSILIFEROUS LIMESTONE OF DELAWARE MOUNTAIN FORMATION

The view was taken in Last Chance Canyon, 26 miles southwest of Carlsbad, New Mexico. The limestone as seen at C is overlain by limestone of Chupadera formation, with limestone conglomerate at base.

An extensive collection from this lower black limestone member made by Mr. Virgil B. Cole contained additional species, as follows:

Palcacis n. sp.
Cystodictya n. sp.
Enteletes dumblei?
Chonetes hillanus?
Chonetes permianus
Productus ivesi?
Productus popei, var. *opimus*
Productus guadalupensis
Pustula aff. *subhorrida* var. *rugatula*
Pustula montpelierensis
Aulosteges n. sp.
Marginifera cucharis?
Camarophoria aff. *venusta*
Squamularia guadalupensis
Spirifer aff. *triplicatus*
Composita subtilita
Hustedia meekana
Hustedia meekana var.
Leda obesa?
Aviculipecten aff. *herzeri*
Acanthopecten sp.
Pleurotomaria sp.
Schizostoma sp.
Omphalotrochus sp.
Platyceras sp.

The relations in the Bone Canyon region and northward are shown in figure 4.

There are also several very striking unconformities in the black limestones some distance below the conglomerate in Bone Canyon, above referred to, which appear to have been caused by local uplift and planation. One of them is shown in plate 14 (lower half).

Delaware Mountain Formation in New Mexico

The thinning of the sandstone member of the Delaware Mountain formation continues to the northward from Bone Canyon, owing to the rise of the surface of the underlying gray limestone member in that direction, and on the New Mexico State line but little more than 100 feet of sandstone remains. However, a fault along the west slope of the mountain in this area, with drag on its downthrown side, conceals the relations of this member farther north. In New Mexico, as explained above, most of the limestone of the greatly thickened lowest member of the Delaware Mountain formation, as well as that of the Capitan, gradually changes to the greenish-gray earthy aspect of the Chupadera formation—a feature which is very striking in the great cliffs in the West Dog Creek region a few miles farther north. Still farther north, near latitude 32° 15′, thick intercalations of gypsum (or anhydrite) and red sediments come in to the Chupadera succession, as shown in section A, figure 3, and sections 1 and 2, figure 4.

It is difficult to trace the northern extension of the lower portion of the Guadalupe group along the east side of the Guadalupe Mountains in New Mexico on account of faulting, flexing, and talus. The upper dark

limestone member of the Delaware Mountain formation is well exposed above Pine Spring, in Texas, where the fossils listed above were collected. Dark, slabby limestones appear again under the typical, light-colored, massive Capitan limestone a few miles north, in McKittrick and Big canyons. From these dark limestones in the mouth of Big Canyon were collected the following:

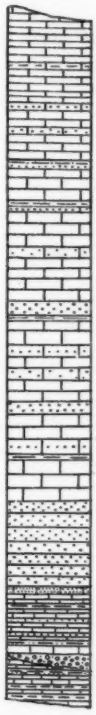
Lophophyllum sp.
**Cladopora spinulata*
**Canocystis richardsoni*
Fistulipora guadalupensis
**Domopora terminalis*
**Domopora ocellata*
Acanthocladia guadalupensis
**Orthotetes guadalupensis*
Streptorhynchus gregarium
**Chonetes hillanus*
Productus semireticulatus var. *capitanensis*
Pustula latidorsata
**Pustula pileola*
**Richthofenia permiana*
Camarophoria venusta
**Pugnoides swallowianus*
**Pugnoides bidentatus*
Rhynchonella longæva
Leptodus americanus
Diclasma guadalupense
Spirifer mexicanus
Martinia rhomboidalis
Squamularia guadalupensis
Ambocœlia planiconvexa var. *guadalupensis*
**Spiriferina billingsi*
Composita aff. *subtilita*
Cliothyridina n. sp.
**Hustedia meekana*
Allerisma aff. *terminale*
Parallelodon aff. *sangamonense*
Aviculipecten n. sp.
Camptonectes sp.
Limatula striaticostata
Pteria guadalupensis
Myalina squamosa
Plagioglypta canna
Phanerotrema sp.
Pleurotomaria planulata?
Euconospira sp.
Bellerophon aff. *crassus*
Naticopsis sp.
Bulimorpha sp.
**Anisopyge perannulata*

These were determined by G. H. Girty, who states that many of the species occur high in the Capitan limestone in the Texas section a few miles south, and there is a lack of many of the species of the upper limestone member of the Delaware Mountain formation at Pine Springs, notably *Fusulina elongata,* which is very abundant at that place. It is possible that there is a great change in the fauna of this member in its extension northward, and it is also possible that in the interval there has developed in the lower part of the Capitan limestone a member of dark, slabby strata. Such a change as the latter would account for the disappearance of at least part of the massive, light-colored rocks of the Capitan limestone to the southeastward in northeastern Texas.

In Last Chance Canyon there is exposed an extensive section of the medial members of the strata in the central ridge of Guadalupe Moun-

* Also collected at Pine Springs, but common to Delaware Mountains and Capitan formations.

tains. The principal features are shown in figure 5. The rocks are mostly limestones in part very sandy, with many characteristics of the Chupadera formation and apparently with no fossils. To the eastward, as shown in sections 2 and 3, figure 2, they dip beneath the thick gypsum member which extends east to the base of the Carlsbad limestone member. To the south they appear to merge laterally into the medial portion



Limestones (Chupadera character).....	350±
Sandy limestones and brown sandy limestones..	300
Buff sandstone, mostly massive and limy.....	50
"Unconformity"?	
Sandy limestone	40
Dark gray limestone; chert nodules.....	
Limestone conglomerate	3–13
Dark slabby limestone; some dark shale.....	
Arroyo.	

FIGURE 5.—*Columnar Section in Last Chance Canyon*
Thirty miles southwest of Carlsbad, New Mexico.

of the Capitan limestone. In the lower part of Last Chance Canyon underlying beds are bared containing many fossils of Delaware Mountain age. The strata are mostly dark, slabby limestones containing a conglomerate member indicating a local intraformational unconformity. The rocks and their general relations strongly suggest the top limestone

member of the Delaware Mountain formation, but the fossils both from above and below the unconformity, appear to indicate a somewhat lower horizon in that formation, but by no chance the lower dark limestone member. The principal fossils collected were determined as follows by G. H. Girty:

Fossils from above the Unconformity, Last Chance Canyon, New Mexico

Fusulina elongata
Lophophyllum n. sp.
Fistulipora sp.
Fenestella sp.
Polypora sp.
Acanthocladia guadalupensis
Enteletes sp. c?
Meekella attenuata
Meekella multilirata
Chonetes hillanus
Chonetes subliratus
Productus aff. *ivesi*
Productus indentatus
Productus popei?
Pustula n. sp.
Pustula subhorrida var. *rugatula*
Pugnoides swallowianus
Pugnoides bidentatus?
Rhynchonella longæva?
Leptodus americanus
Spirifer aff. *triplicatus*
Spiriferina billingsi
Composita mexicana
Hustedia meekana
Parallelodon n. sp.
Aviculipecten sp. b
Pleurophorus? n. sp.
Astartella nasuta
Plagioglypta canna?
Bellerophon n. sp.
Pleurotomaria multilineata
Pleurotomaria n. sp.
Omphalotrochus n. sp.
Orthonema n. sp.
Bulimorpha chrysalis var. *delawarensis*

Fossils from below the Unconformity, Last Chance Canyon

Fusulina sp.
Lophophyllum sp.
Echinocrinus sp.
Enteletes sp. c?
Derbya n. sp.
Meekella attenuata
Meekella sp.
Pustula subhorrida var. *rugatula*
Aulosteges guadalupensis?
Richthofenia permiana
Pugnoides osagensis
Pugnoides bidentatus
Camarotæchia pusilla?
Rhynchonella aff. *indentata*
Spirifer aff. *triplicatus*
Composita mexicana?
Hustedia mormoni?
Parallelodon 2 sp.
Aviculipecten aff. *interlineatus*
Pleurophorus sp.
Plagioglypta canna
Euphemus sp.
Pleurotomaria aff. *planulata*
Schizostoma sulciferum var. *angulatum*
Naticella sp.
Meekospira sp.
Bulimorpha sp.
Griffithides sp.

This dark, slabby limestone member is again revealed in Rocky Arroyo, in the southeastern corner of township 22 south, range 21 east, where some of the same fossils were found.

G. H. Girty makes the following comments on the fossils from the Last Chance Canyon:

"The fauna has a decidedly different facies from that from Big Canyon, a facies which I regard as Capitan, as well as from that in the upper dark limestone at Pine Springs and southward. So far as it goes, it indicates equivalency with members in the sandstone of the Delaware Mountain formation. It includes but few types that have not been found at this horizon and a good many that have never been obtained above it. The fossils from the sandstone or sandy limestone above the unconformity contains a large number of *Fusulina elongata*, many sponges of various species, and an abundance of a large *Spirifer* (*Spirifer b* in Professional Paper 58) of the triplicatus type, which occurs both in the sandstone and the lower dark limestone members."

We might add the suggestion that the sandy sediments may have influenced the fauna at a horizon materially different from the sandstone of the Delaware Mountain formation.

The discovery of these Guadalupian fossils in limestone members of the Delaware Mountain formation in the canyons of Last Chance and Rocky arroyos is of great importance, for it shows that the overlying Chupadera limestones constituting the Guadalupe Mountain to the north and west have the same position as the Capitan limestone into which they merge to the southward. The structure is so obvious that separation by faults or overlaps seems out of the question. As stated above, the relations exposed in townships 25 and 26, ranges 19 and 20, also show that the lower limestone members of the Delaware Mountain formation (both black and gray) merge into the lower part of the Chupadera formation. Therefore it is believed that this formation represents the northern extension of the Delaware Mountain formation and Capitan limestone.

Faunal Changes

The complete change of fauna from Guadalupian to Manzano from south to north doubtless is due, as suggested by Girty and Richardson, to difference in environment, probably the different character of the seas in the two portions of the general basin. The precise conditions are difficult to suggest, for the confines and configuration of the basins are not known. The great deposits of gypsum in the Chupadera succession in central and southern New Mexico, with thick beds of salt to the eastward, indicate desiccation, while the thick body of pure limestones of the Capitan evidently were deposited in an open sea. The Guadalupe fauna was found as far north as township 24 south, on the west side of Guadalupe Mountains, and also near Carlsbad Cave, in about the same latitude, on the east side, where the following were collected:

Sponges, sev. gen. and sp.
Orthotetes guadalupensis
Streptorhynchus gregarium
Auslosteges? n. sp.
Camarotœchia n. sp.
Diclasma scutulatum
Cliothyridina n. sp.
Parallelodon sp.
Aviculipecten laqueatus
Aviculipecten aff. *occidentalis*
Aviculipecten n. sp.
Camptonetes asperatus
Pteria guadalupensis
Myoconcha n. sp.
Plagiostoma deltoideum
Bucanopsis sp.
Pleurotomaria richardsoni
Pleurotomaria n. sp.
Naticopsis n. sp.
Orthoceras n. sp.
Foordoceras shumardianum

They were determined by G. H. Girty.

Farther north, in the Guadalupe Mountains as well as in the Sacramento Mountains and northward far across New Mexico, the Manzano fauna prevails, as shown by abundant collections. A detailed account of these rocks and associated formations is now ready for publication as a Professional Paper of the United States Geological Survey.

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UPPER CRETACEOUS SHORELINE IN UTAH[1]

BY EDMUND M. SPIEKER AND JOHN B. REESIDE, JR.

(*Read before the Geological Society December 29, 1925*)

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INTRODUCTION

It is the purpose of this paper to record briefly stratigraphic data collected in 1924 and 1925 along the western margin of the Wasatch Plateau; to correlate it with data previously recorded for the other regions to the south and north; and to interpret on the basis of the correlation the probable position of the Upper Cretaceous shoreline at several periods during the history of the region.

The westernmost Cretaceous deposits of Utah appear in more or less isolated areas along a line extending through Cedar City at the southwest and Coalville at the northeast. The localities important in the present discussion are those in the Colob Plateau, near Cedar City; the western edge of the Wasatch Plateau near Manti and Salina; the Blacktail Mountain district, in the western Uinta Basin; the Coalville region; and the region near Evanston, Wyoming. Several other areas of Cretaceous rocks also lie in this belt, but are not known sufficiently well to be of service.

[1] Published by permission of the Director, U. S. Geological Survey.
Manuscript received by the Secretary of the Society March 1, 1926.

The Cretaceous of the Kaiparowits Plateau, of the Henry Mountain area, of the eastern front of the Wasatch Plateau, and of the Book Cliffs also enter into the discussion.

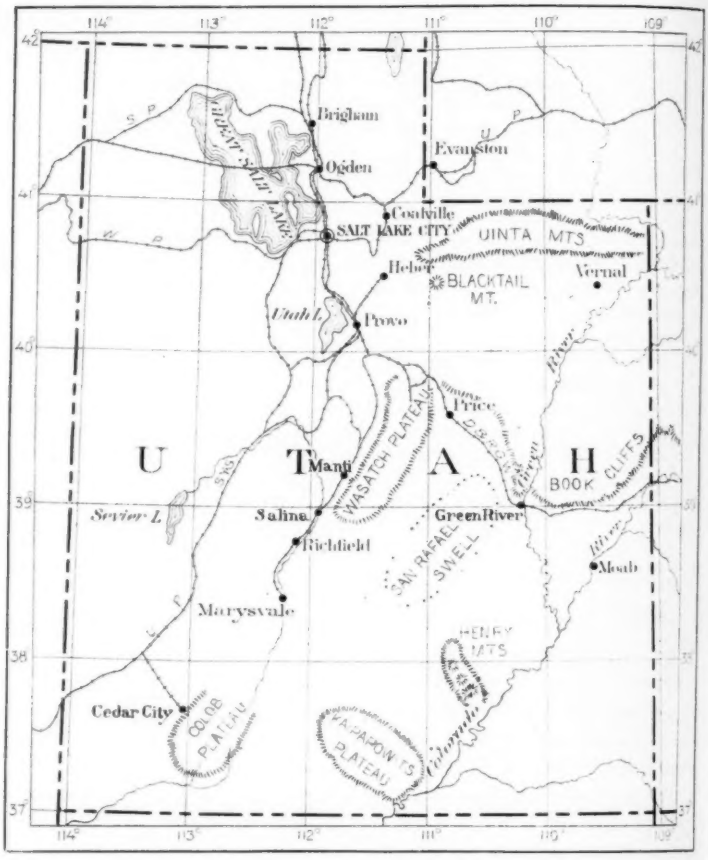

FIGURE 1.—*Index Map of Regions referred to in the Paper*

The data used for the Colob Plateau were gathered by Stanton in the early nineties and Richardson in 1907. Part have been published,[2] part

[2] T. W. Stanton: The Colorado formation and its invertebrate fauna. U. S. Geol. Survey Bull. 106, 1893, pp. 34-36.

G. B. Richardson: The Harmony, Colob, and Kanab coal fields. U. S. Geol. Survey Bull. 341, 1909, pp. 379-400.

are unpublished. The data for the Blacktail Mountain region were collected by Lupton[3] in 1910. The data for the Coalville region resulted from work by Stanton[4] in the early nineties and by Wegemann[5] in 1912. For the region near Evanston, Wyoming, the data were gathered by Stanton[6] in the early nineties and by Veatch[7] in 1905. For the Henry Mountain region the data used are due to visits to the area by James Gilluly and the writers. For the Kaiparowits Plateau information was supplied by Professors H. E. Gregory and R. C. Moore. For the eastern Wasatch the previous paper[8] by the writers is the source.

The various studies listed above have all been to a certain extent isolated and have not been welded together to present a broad picture of events in Upper Cretaceous time. The paleontologic data available, however, permit a fairly satisfactory correlation throughout and a better understanding of the successive changes in the region than can be gained from the separate studies themselves.

Section in the Manti-Salina Region

At the base of the monocline forming the west flank of the Wasatch Plateau erosion has at several places cut through the Tertiary rocks to lay bare steeply dipping Upper Cretaceous beds. Near the mouth of Salina Canyon the Cretaceous beds appear in a narrow inlier where Salina Creek has cut through the surface of unconformity between Wasatch and pre-Wasatch beds. Near Manti the Cretaceous beds appear in a series of hogbacks and promontories, where they have been uncovered by general erosion of the lower plateau slopes and the eastern part of San Pete Valley. Other areas east of these show isolated exposures of late Cretaceous rocks, but are not pertinent here.

The section in and near Sixmile Canyon, about four miles south of Manti, shows the entire sequence except the lowest Colorado beds. That in the lower part of Salina Canyon shows all of the early Colorado, the middle Colorado, and part of the late Colorado beds. The strata in these places do not fit into the lithologic classification used farther east, but new formation names have not been applied here because they are not

[3] C. T. Lupton: The Blacktail (Tabby) Mountain coal field, Wasatch County, Utah. U. S. Geol. Survey Bull. 471, 1912, pp. 595-628.

[4] T. W. Stanton: Op. cit., pp. 37-44.

[5] C. H. Wegemann: The Coalville coal field. U. S. Geol. Survey Bull. 581, 1915, pp. 161-184.

[6] T. W. Stanton: Op. cit., pp. 45-46.

[7] A. C. Veatch: Geography and geology of a portion of southwestern Wyoming. U. S. Geol. Survey Prof. Paper 56, 1908.

[8] Edmund M. Spieker and John B. Reeside, Jr.: Cretaceous and Tertiary formations of the Wasatch Plateau, Utah. Bull. Geol. Soc. Amer., vol. 36, 1925, pp. 435-454.

essential to the present discussion. A generalized section, derived chiefly from Sixmile Canyon and supplemented in the basal part by data derived from Salina Canyon, is as follows:

Section of Upper Cretaceous Rocks exposed in the Manti-Salina Region

	Feet
Wasatch formation, resting with marked angular unconformity on all the preceding beds.	
Upper Cretaceous:	
Late Montana:	
1. Sandstone and conglomerate, gray to buff; several massive layers up to 30 feet thick; pockets of conglomerate scattered throughout except in lower 35 feet; cobble bed 30 feet thick 100 feet beneath top; pebbles chiefly quartzite and all rounded. No fossils observed	425
2. Coal-bearing series; fine to medium grained sandstone, white, cream, and buff; shale—gray, brown, and white; fireclay; thin beds of coal; a little conglomerate near the top and base. Fossil plants	310
Probably late Montana:	
3. Conglomerate, grit, and coarse sandstone, gray, massive, and very prominent. No fossils observed	2,100
Late Colorado:	
4. Sandstone, cream-colored in the main, with minor white and brown layers; some pebble beds containing marine fossils.	700
5. Shale, gray, sandy. Marine fossils at top	650
6. Sandstone; upper 200 feet cream-colored and interbedded with thin layers of gray marine shale; next lower 650 feet brown, in ledges 5 to 10 feet thick, interbedded with thinner layers of yellow sandstone and yellow-gray sandy shale; basal 50 feet of gray-weathering, cream-colored massive sandstone. Marine fossils in lowest part	900
Middle Colorado:	
7. Shale, gray, marine, with many thin layers of bentonite, gray limestone and fine-grained sandstone. Marine fossils	620
Early Colorado:	
8. Sandstone, brown, buff, and gray, fine to coarse grained; thin beds of sandy shale, mostly yellow, but in the lower part streaked with red; some grit and conglomerate in upper part, much in lower part. Marine fossils in upper 600 feet, none observed below	2,200
	7,905
Cretaceous (?):	
Beds of variegated shale very much like the Morrison formation of eastern Utah.	

Units 1, 2, and 3 are lithologically similar—coarse, massive in the main—and are much like the beds of accepted late Montana age in the other regions in the Colob-Evanston belt. They are similar also to the Price River formation[9] at its nearest exposures, referred on the basis of fossils to the late Montana. Some of the sandstone layers of unit 2 contain poorly preserved fossil plants, identified by Dr. F. H. Knowlton as indicating late Montana age, a corroboration of the age suggested by the lithology. The thickness of unit 3 suggests that it might include beds older than late Montana, though the lithologic change from unit 4 to unit 3 is so pronounced as to suggest a considerable break in the sequence, and it seems unlikely that much of the earlier Montana is present.

Unit 4 contains a marine fauna of late Colorado age. Unit 5 has not yielded a diagnostic fauna, but it is undoubtedly marine. Unit 6 has yielded typical *Inoceramus erectus* Meek from the basal part, which determines its age as late Colorado.

The identity of units 4 to 6 is not entirely certain because of some latitude in the interpretation of the structure. It is possible that the shale units 5 and 7 are the same, that the unit 4 and the lower part of unit 6 are the same, and that the upper part of unit 6 and unit 8 are the same, due to repetition by faulting. If the shales are the same, the late Colorado beds are 900 feet thick instead of 2,250, as given in the section above. The chief argument to the contrary is that to duplicate the shale the fault between the two exposures would have to be far too great in displacement to harmonize with the structural data available in near-by exposures. The solution of the problem does not affect the present discussion very materially, as the sequence of faunas is recognized in either case.

Unit 7 contains a middle Colorado fauna at both Sixmile and Salina canyons. The number of species is small, but included forms, such as *Prionotropis woolgari* Mantell, are diagnostic. Unit 8 has not yielded fossils at Sixmile Canyon, but at Salina Canyon it contains an unmistakable lower Colorado fauna in the upper fourth. The lower three-fourths of this unit are so nearly identical with the upper fourth in lithology that, in spite of the lack of fossils, it is not logical to attempt any separation of the lower from the upper part. The base is a conglomerate and rests upon shales of Morrison aspect.

Sections in Utah and Wyoming

The accompanying diagram, figure 2, presents in graphic form the stratigraphic sections from which are drawn in large part the data pre-

[9] Edmund M. Spieker and John B. Reeside, Jr.: Cretaceous and Tertiary formations of the Wasatch Plateau, Utah. Bull. Geol. Soc. Amer., vol. 36, 1925, pp. 446-448.

sented in the series of maps. These sections are specific sections, selected as representative of the separate regions, but are generalized as regards lithologic details. The first group is intended to show the variations in thickness and general lithology from Colob Plateau to Evanston. The second group shows the variations in the area east of the first.

Paleontologic Zones

In the sections present in the areas interpreted in this paper several paleontologic zones may be recognized. These serve as the basis of the chronologic divisions adopted in depicting the inferred paleogeographic features of the region.

In the lower part of each section a fauna of early Colorado (lower Benton) age is discernible, including *Metoicoceras whitei, Inoceramus labiatus, Ostrea soleniscus, Mactra emmonsi, Corbula kanabensis,* and numerous other species.

Next above it appears a fauna of middle Colorado (upper Benton) age, with several species of *Prionotropis* as the most conspicuous element.

Then a fauna of late Colorado (Niobrara) age, with *Inoceramus erectus* as its most conspicuous species, together with *Mactra utahensis, Baculites* aff. *B. anceps,* and other species. In some places the involute *Inoceramus umbonatus* also occurs.

In the westernmost Cretaceous the Niobrara fauna is the highest marine fauna present, the succeeding beds, of Montana age, up to the top of the Cretaceous containing only nonmarine species. The Montana group in the eastern part of the Wasatch Plateau, however, contains a marine fauna of lower Montana age; the region farther east, one of middle Montana age also. The latest Montana in Utah is everywhere nonmarine, and the nearest marine occurrences of late Montana age are in the Yampa Valley, Colorado.

Sediments and their probable Relation to the Shoreline

General statement

The accompanying series of maps is intended to show, necessarily in a much generalized fashion, the predominant kinds and the distribution of the sediments at each of the six stages of the Upper Cretaceous mentioned above—early, middle, and late Colorado and early, middle, and late Montana. The inferred shoreline is drawn on each map at the shoreward limit of marine deposits, though to do so includes on the seaward side some deposits of nonmarine origin in the zone over which the smaller variations took place during the interval represented by the map.

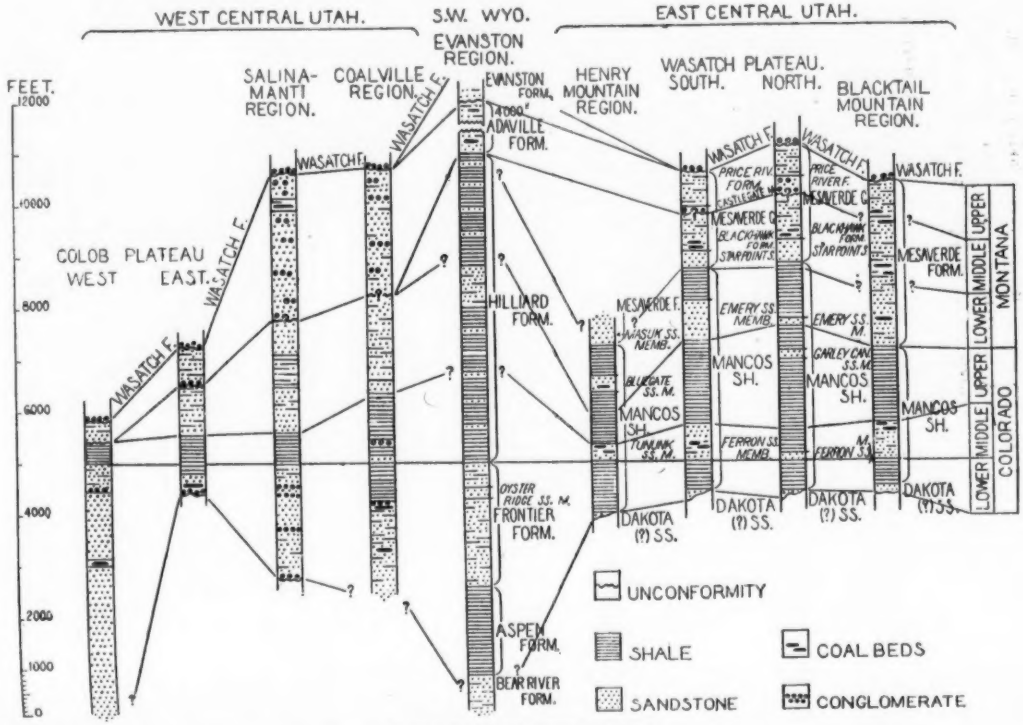

FIGURE 2.—*Stratigraphic Sections*
Representing regions in Utah and Wyoming which have yielded data used in the series of maps.

EARLY COLORADO (LOWER BENTON) TIME

In southwestern Utah during lower Benton time the predominant sediments were sands, much thicker in the western part of the Colob Plateau than in the eastern part and locally including coal beds. In the lower part brackish water fossils, in the upper part marine predominate. In the region near Manti and Salina a thick sandstone unit containing much conglomerate and with marine fossils in the upper part was laid down.

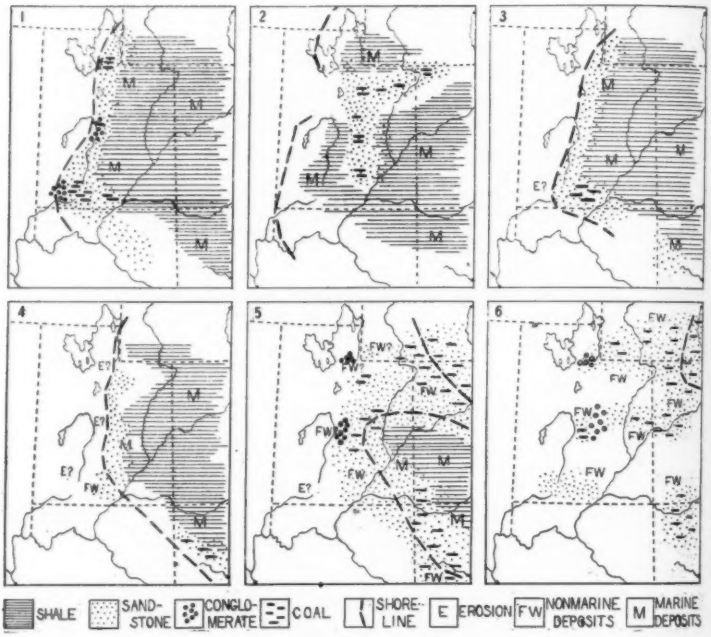

FIGURE 3.—*Series of Maps*

Showing in generalized form the varying shorelines and distribution of lithologic types in Utah in Upper Cretaceous time. 1, Early Colorado time; 2, Middle Colorado time; 3, Late Colorado time; 4, Early Montana time; 5, Middle Montana time; 6, Late Montana time.

In northern Utah coal-bearing sandstone with many marine fossils is the conspicuous element. In adjacent Wyoming a thick shale of peculiar type, the Aspen shale, is succeeded by a thick marine sandstone series. There is, in short, a belt of sandy sediments extending from southwest across north-central Utah—a belt of littoral materials. Eastward from

this belt marine shales are the conspicuous sediment, with a thin and variable basal sandstone at many places—offshore sediments.

MIDDLE COLORADO (UPPER BENTON, CARLILE) TIME

In southwestern Utah during middle Colorado time marine shales were laid down where sandstones had been deposited during the previous stage. This was also true for the Manti-Salina region. Apparently the zone of coarser sediments had moved westward to some line not now known. In northern Utah the sediments of this interval began with some sand and a little conglomerate; then passed quickly into shale, the conspicuous element. In southwest Wyoming shales only were laid down. East of these areas of fine sediment was laid down a notable deposit of coarser material, chiefly marine, but in part coal-bearing, that extended over a large area in central and northeastern Utah where shale had prevailed during the preceding period. It reached from the Henry Mountains on the south, beyond Blacktail Mountain on the north, and northeastward into northwest Colorado and adjacent Wyoming. East and southeast of this sandstone area shale only was laid down. There seems thus to have been a peninsula-like accumulation of sandy sediments with an embayment of shaly sediments on the southwest, another on the north, and the main body of offshore sediments to the east. The sandy area connected westward, it seems likely, somewhere between Coalville and Manti with the shore zone whose position is now unknown, though probably not a great distance away.

LATE COLORADO (NIOBRARA) TIME

In southern Utah, during Niobrara time, sandy marine sediments were laid down, coal-bearing in the Kaiparowits Plateau. In the Manti-Salina region, also, sands were the predominant sediment. In north central Utah and adjacent Wyoming sand was again the conspicuous element. To the east only shales with some thin limestone bands are known. At this time, therefore, conditions were much as in lower Colorado time—a belt of sands extending from southwest to north central Utah as a shore zone and east of it only fine offshore sediments.

EARLY MONTANA (LOWER PIERRE, TELEGRAPH CREEK, AND EAGLE) TIME

In the belt running from Colob Plateau through Manti and Salina to Coalville no deposits, certainly of early Montana age, are known. The nonmarine beds which succeed those of Niobrara age in Colob Plateau are of late Montana age, and there may have been erosion during early and middle Montana time. In the Manti-Salina region coal-bearing

beds of late Montana age are preceded by a considerable thickness of coarse sediments which may possibly extend down into middle or early Montana, but are more likely all of late Montana time. In the Coalville region a series of deposits similar to those near Manti may likewise extend downward into middle or early Montana, though again it seems more likely that they are largely, if not entirely, of late Montana age. In southwestern Wyoming the beds immediately succeeding the Niobrara are marine shales. East of the Colob-Coalville belt some shales, but chiefly marine sands, mark the lower Montana in a second belt from the Henry Mountains[10] through the eastern Wasatch Plateau to the Blacktail Mountain region. Still farther east the sediments are almost entirely shale. The sea therefore retreated somewhat in early Montana time from the area previously occupied.

MIDDLE MONTANA (UPPER PIERRE) TIME

Nonmarine beds, probably of middle Montana age, are present in the Henry Mountains, in the eastern Wasatch Plateau, and probably in the Uinta Basin area. Marine sandstones and shales occur only in a limited region farther east. The withdrawal of the sea is markedly greater than that shown in the previous interval, though there was still a large embayment in eastern Utah.

LATE MONTANA (FOX HILLS, FRUITLAND-KIRTLAND) TIME

Nonmarine deposits, locally coal-bearing, of late Montana age are widespread in Utah. They are known in the Colob Plateau, Kaiparowits Plateau, Salina-Manti region, eastern Wasatch Plateau and Book Cliffs, Coalville region, and possibly in the Adaville formation of southwestern Wyoming. The nearest marine deposits are far to the east. The sea has completely withdrawn.

SUMMARY

The sea in early Colorado time advanced rather rapidly westward to west central Utah, where its zone of oscillation is marked by a belt of sandy sediment accumulated during a considerable period. Then, in middle Colorado time, it advanced somewhat farther westward; but the advance of the waters was divided by a peninsula-like area of shallow waters extending into the region where one would have expected deeper waters. In late Colorado time a retreat began, at first rather slow, then more rapid, and by late Montana time the entire region was receiving only fresh-water deposits and the sea was far to the east.

[10] Recent collections show that the upper part of the "Bluegate shale" and the overlying Bluegate sandstone are of early Montana age.

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HYPOTHESIS OF MOUNTAIN-BUILDING[1]

BY E. C. ANDREWS

(Presented before the Society December 30, 1925)

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INTRODUCTION

The accompanying note has been prepared as a result of the published papers on "mountain-building" in the Bulletin of this Society for 1923, and it may be considered as a natural continuation of the discussions in that symposium. Much assistance also has been derived from a consideration of the recent papers by R. A. Daly,[2] H. A. Brouwer,[3] F. B. Taylor,[4] W. Bowie,[5] and W. D. Lambert.[6]

[1] Manuscript received by the Secretary of the Society September 10, 1925.
The present paper was foreshadowed in an earlier contribution to the Bulletin of the Geological Society of America (1923), and is based, in part, on the symposium of which the earlier paper formed a part.

[2] Quoted from abstract in Science, n. s., vol. lxi, no. 1583, 1925, p. x.

[3] The major tectonic features of the Dutch East Indies. Jour. Wash. Acad. Sci., vol. 12, no. 7, 1922, p. 173.

[4] Movement of continental masses under action of tidal forces. Pan American Geologist, vol. xliii (February, 1925).

[5] The yielding of the earth's crust. Smithsonian Report, 1921, p. 240.

[6] The Mechanics of the Taylor-Wegener hypothesis of continental migration. See also, in this paper, article by Taylor, entitled The lateral migration of land masses; also, by R. A. Daly, a critical review of the Taylor-Wegener hypothesis. Proc. Wash. Acad. Sci., vol. 13, no. 20, 1923.

To all the authors of the various contributions to the Bulletin mentioned above and to the other authors mentioned individually the writer desires to express his great indebtedness.

The hypothesis of mountain-building outlined herewith was foreshadowed in the contribution by the writer to the symposium under consideration. The ideas presented herein do not suggest that the other methods of approach to the subject of mountain-building are incorrect. It simply presents the case from a new viewpoint, and its possible merit lies in the fact that it furnished a very simple explanation of the origin of mountains, based upon their known forms, together with their geographical distribution.

Mountain ranges are earth undulations, which are mutually supporting and are due in the main to relief upwards of pressures, at moderate depths below the surface, exerted by rock material tending to undergo "rock flowage." The movement is extremely slow and allows overthrusting and gliding phenomena without serious disturbance of isostatic conditions.

General Form of the Earth's Surface in Plan

At the outset it appears necessary to take a general review of the known facts of form with regard to the departure of the earth's surface from a geometrical form.

The first point which impresses the observer is the approximation of the geoid to a spheroid of revolution, the equatorial diameter exceeding the polar one. Closely related to this is the relatively slight amount of vertical relief obtaining over the earth's surface as compared with the earth's radius. The highest mountain does not rise 6 miles above the ocean surface; neither does the greatest ocean depth known to scientific workers exceed 6½ miles. Moreover, the summit levels and the trough depths occur only within narrow zones of limited length. The average depth of the ocean is from 2½ to 3 miles, while the average height of the continents is less than half a mile above sealevel. The greater portion by far, both of ocean base and continental surface, is devoid of noticeable and abrupt relief, if not even monotonously level. It is accepted as the normal state of things that the ocean should occupy three-quarters, approximately, of the surface of the earth; nevertheless, that its average depth should not exceed one fifteen-hundredth of the length of the earth's radius. It is, however, more than a coincidence that the ocean depth is almost uniform over an area exceeding 100,000,000 square miles, nevertheless almost imperceptible to the unaided eye if represented to

proper scale on a globe 3 feet in diameter. The mere shape of the earth suggests, on the one hand, that the base of the ocean generally is determined by a widespread leveling action by "rock flowage,"[7] tending to reduce irregularities in the earth's crust, and that continents are buoyed up above the suboceanic masses, nevertheless tending also to find their own level mainly by rock distortion without rupture except as an incident in the process, and, on the other hand, that the general shape of the surface is controlled by earth rotation, in which the time factor is exceedingly long.

In the second place, enormous areas of the continents are occupied by wide, shallow structural depressions, which have the general appearance of valleys and which possess a rude alignment with the nearest oceans or with the great "hinge" areas of the continents. Examples of the foregoing are the great plains and prairies of North America, the savannas of South America, the Siberian and north European plains, the Gobi-Kashgar-Oxus system, the center of Africa, and the great north-and-south depression of Australia. These have a general appearance of earth-wave troughs.

In the third place, the zones of major relief and depression—with the marked exceptions noted below—are arranged in directions which approximate to the meridians rather than to the parallels of latitude. Examples of this are the American Cordillera, the Greater Appalachians, the Atlantic ridge, the East African ranges and the Rift Valley system, the Ural system, and the plateaus of eastern Asia, together with those of Australia. Exceptions are found in the subequatorial belt of the Tethyan and Antillean mountain ranges and the wonderful vertebra system of cross-mountain ranges which extends from the Pamirs toward Bering Strait, including the Alai, Tien Shan, Ala Tau, Altai, Sayan, and Vittim, together with other great ranges in this group, which overlook the Siberian plains to the north.

In the fourth place, the eastern continuations of the Tethyan and Antillean mountain groups have the appearance of undulations produced by the interaction of forces acting from the north and south.

In the fifth place, the West and East Indies appear to occupy mobile areas suggestive of continental "hinges." This is true also of the Tethyan system of mountains, which occupies a mobile area many thousands of miles in length, separating northern Eurasia from Africa south of the

[7] By "rock flowage" is implied deformation of rocks without conspicuous fracture, remaining at the end of the deformation as an integral body. C. K. Leith, Structural Geology, 1913, p. 76.

plateaus facing the Mediterranean, from Arabia also, together with peninsular India and Australia.

The Ural Mountain system also appears to occupy an ancient "hinge" area.

In the sixth place, it may be noted that modern mountain ranges are arranged subparallel to continental margins, to the general axes of islands from which they rise or which indeed they may constitute, or to the general directions of the main axes of the larger geosynclines of today or of the past, such as the Tethyan Mediterranean, the Ural "hinge," or the Greater Appalachian geosyncline. Excellent examples of this feature are the island arcs of the Pacific, the East and West Indies, Africa, peninsular India, eastern Australia, the Ural Mountains, and the American Cordillera.

In a general way the grand sweep or trend of mighty ranges—that is, plateaus—follows the trends either of old geosynclines or mediterraneans. Examples are the Tethyan arcs, the American Cordillera, the Appalachian ranges, the "Australian Island arcs." For example, we may have the European Alps, the Carpathians, the Balkans, the Persian Mountains, the Greater Himalaya, and the East Indies, forming huge knots or bulges with curves which appear to point to all points of the compass, and upon casual inspection are, apparently, unrelated to each other; nevertheless on a general or bird's-eye view they may be seen to have originated in the upheaval of the sediments and igneous rocks of the Tethyan area and to be due to some dominating control along that ancient "hinge area." In other words, these mountain systems are arranged subparallel to Tethys; nevertheless the strikes of individual mountain groups diverge very materially from the trend of the general axial uplift. Moreover, these ranges have plunging crests.

In the seventh place, the convexity of the mountain arcs, and island arcs also, may be directed either toward the nearest ocean or continental plain or it may be determined by its position, in a general way, in both directions from the main axes of the "hinge," as though the earth undulations had spread out over their own bases toward areas of least pressure in their escape from the zone of deep subsurface pressure. Examples are the American Cordillera, Alps, Moroccan system, Asia Minor Mountains, Persian Mountains, Pamirs, Himalaya-Tibet-Kuen Lun system, the Ural system, East Indies, West Indies.

Form of Mountains in Section

The next division which it may be advisable to consider deals with some other general qualities of mountains.

In the first place, all modern mountains are plateaus in the form of earth waves or undulations. The plateaus proper are roughened or diversified by structural undulations subparallel to their main axes, while the plateau margins are formed of higher subparallel ranges or earth undulations. Examples are the plateau of Tibet, with the Kuen Lun and Altyn Tagh on the north and with the Trans-Himalaya and the Himalaya proper on the south; the basin ranges of the United States, with the Rocky Mountains on the east and with the Sierra and other ranges on the west; the Puna and other central plateaus of the Andes, with the Cordillera Real de los Andes and other great ranges to the east and the Cordillera de los Andes and its extensions to the west; the Pamirs, with the Hindu Kush and the Alai ranges on the north and south respectively. The Asia Minor plateau, the eastern Australian plateau, and other areas form additional excellent illustrations.

In the second place, the margins of the plateaus proper are warped or folded to the intermontane valleys, or to the fore-deeps or plains under the ranges, in a series of lesser ranges and foothills of decreasing height. These ranges and foothills are structural forms, and their longer axes lie subparallel to those of the main ranges or plateau margins. Moreover, the intermontane valleys are structural forms and are of the same age as the associated plateaus. Each appears to be an earth wave or undulation with irregular and plunging crests, as in the case of natural undulations formed in mobile or plastic material.

Furthermore, these plateau ranges and their subsidiary forms are narrow and roughened in proportion to their height. Examples of this are the Himalaya with the Lesser Himalaya and the compound lines of the Siwaliks; the American Cordillera, both on its eastern and western aspect. Examples of broad, low plateaus are found with the Canadian, Brazilian, and western Australian shields.

In the third place, the modern Alpine plateau types appear to be revivals of late Mesozoic and Tertiary uplifts, due allowance being made for the advance or retreat of the general axis of elevation which closed the long intervals of relative quiescence and erosion.

In this connection the accompanying extract from Brouwer is very instructive:

"The Tertiary folds and overthrusts which were formed at relatively great depths are now visible at the surface, but the fissured and faulted crust that

once lay above them has been removed by erosion. On the other hand, the tectonic features due to late deformation near the earth's surface during the younger stage of mountain-building have remained visible and are manifested in the fissured and faulted crust, while the accompanying folds and overthrusts remain invisible at greater depths."[8]

In the fourth place, the elevation of plateaus appears to take place with exceeding slowness, as is indicated by the persistence of stream courses against land masses rising against the direction of their flow. This elevation is accomplished in stages with pauses of relatively stable equilibrium.

This slowness of mountain movement, both in vertical and lateral directions, is a point needing consideration in discussions on earth undulations, "rock flowage," and isostasy.

In the fifth place, the continental nuclei or arcs are composed of ancient rocks which have been subjected to the action of intense folding and overthrusting, but which now are relatively stable. Mountain-building, on a grand scale, appears to have passed gradually away since Archean time until the present from the innermost arcs toward the outermost, the latter alone being the scene of orogenic activity at the present time.

One group appeared to pass southward toward Tethys, another toward the Atlantic, and still another toward the Pacific. The action of intense folding appeared to desert the inner nuclei long before the close of the Paleozoic; the Atlantic system appears to have closed with the Paleozoic, whereas the action within the Tethyan area and within the Pacific is very pronounced even today. Nevertheless, active as the forces of mountain-making are today in these outer zones and arcs, it may be noted that pre-Cambrian folding of intensity occurred within these outer arcs themselves. Perhaps the main point to bear in mind, in the discussion on "rock flowage" and isostasy, is that the growth of interarc stability progressed from the inner nuclei toward the outer.

In the sixth place, modern mountains of great size appear to move outward over their bases, as though they were being elevated to great heights and were escaping from the upward pressure, in part, by the assumption of lateral movement, with the production of huge overthrusts which fold the outwash gravels of the mountains in the process. Examples are the Himalaya, Kuen Lun, Tien Shan, Hindu Kush, the European Alps, the Caucasus, the Pyrenees, and, in all probability, the American Cordillera.

[8] H. A. Brouwer: The major tectonic features of the Dutch East Indies. Jour. Wash. Acad. Sci., vol. 12, no. 7, 1922, p. 173.

Hypothesis of Mountain Formation

In this connection we may consider the work of the geodesists. Prominent among these workers are Bowie and Burrard, the reasoning advanced by Bowie being especially pertinent:

> "As there is today an isostatic balancing of the blocks of the earth's crust under various classes of topography (that is, different degrees of elevation), and as it is reasonable to assume that this balance has obtained in past geological periods, we have to conclude that mountain systems are not due to horizontal movements of the crust resulting from forces acting in a horizontal direction from great distances from the affected regions. Should there be such horizontal movements, we would be forced to believe that extra loads were placed on blocks which were previously in isostatic equilibrium."[9]

The observed facts of great overthrusts, as recorded in the cores of ancient mountain ranges, do not appear to be opposed to the hypothesis of mountain-making by vertical uplift, or, stated in another way, by the formation of great earth undulations. For the general appearance of the continents and the oceans, together with the typical forms of plateaus, suggests that they are mutually supporting on some subsurface development of extremely slow rock deformation without sudden rupture, and that they are in a condition of isostatic equilibrium to the varying depths at which the forces producing the plateaus or earth undulations are operating effectively. It is reasonable to expect, as maintained by Bowie, that the crust has been in a condition of isostatic equilibrium from the Archean onwards. Overthrusting, on an enormous scale, is quite consistent with the production of plateaus or earth undulations if the factor of enormous time be taken into account. Take, for example, the case of the great deeps of the Pacific Ocean today with their associated island arcs or the case of an aggraded trough such as the Gangetic plain and the associated Himalaya. In the case of an ocean trench such as the Tongan, or Japanese, Deep, there is the structural hollow 6 miles below the ocean surface; thence a long slope leads to a front range, plateau, or island arc. Behind this, in turn, lies a sea trough or intermontane valley, while beyond this structural trough lies a line of volcanoes, rising from older denuded volcanic material. The undulation is growing, or has grown very recently, the axes of the troughs and of the volcanic lines advance or retreat, and material is continually passing from the trough area during such movement and material is being piled upon or brought under the island areas. Notwithstanding this, the gravity anomalies are apparently negligible. This is explicable owing to the

[9] William Bowie: The yielding of the earth's crust. Smithsonian Report, 1921, p. 240.

vast time occupied in the transmittal of the material, generally, in undulatory manner, the undulations or waves being mutually supporting. In all probability portions of these masses are actually flowing laterally or outward over themselves from the upward pressure of the undulatory force, thus giving rise to great overthrusts or glides, yet so slowly that the mutually-supporting action is not disturbed suddenly, with production of rapid dislocation, but is maintained continuously, such that no extra load is imposed upon the area undergoing folding. This conception may be appreciated more readily because the natural overthrust is toward the convexity of arc—that is, toward the "deep." The convexity of the Himalaya to the Gangetic plain is such as to indicate an enormous overthrusting of the range toward the plain, the angle of the plane of movement being estimated at 14 degrees.[10] This is readily conceivable as a lateral component of a general vertical or undulatory movement, the surface thus produced appearing as a great compound earth wave. The core of a range such as this would exhibit slow mashing phenomena with overthrusting toward the margins, and the outwash sediments in the foothill country would be folded gradually by the overthrusting or "flowage" outward of the range with the passage of geological time.

In this way also it is easy to appreciate the overthrusting action from the mobile geanticline area toward the loaded geosyncline. The basin structures have been taxed beyond their strength; the neighboring earth wave or mobile geanticline develops an overthrust or gliding plane, which almost imperceptibly moves into the trough area, involving the marginal sediments there. This process is repeated, the overthrusting and folding action advancing beyond its former limits on each occasion until the whole area attains a measure of relative stability. The whole of the geosyncline may not be affected, the outer portion perhaps suffering little or nothing from the overthrusting near the mobile geanticline. Examples of this differential action are common in all countries. It would appear from a study both of modern mountains and the cores and middle portions of denuded mountains that their formation admits of simple explanation as earth waves mutually supporting at any particular instant, and that great overthrusts take place under the action of gravity as relief is sought from upward movement. Faults developed thus would be of compressive type in the main.

Suess considered that mountain ranges, such as the Himalaya, were formed by a movement of the earth's crust directed from the continental

[10] P. Lake: Article Himalaya, in Encycl. Brit., eleventh edition.

nucleus, his Siberian "vertex." Hobbs,[11] with others, on the other hand, considers the great mountain ranges to have been determined by suboceanic thrusts with a backward movement from the continental margin.

If the thrusts do come from the suboceanic mass, then it is necessary to explain the manner in which they pass under Africa, Arabia, peninsular India, and Australia, such that these great stable masses have been apparently affected in a slight degree only. Nevertheless the Tethyan area itself, lying beyond these stable massifs, had had mighty mountain ranges developed within itself on several occasions since the Middle Cretaceous period.

Explanation of Facts stated in foregoing Paragraphs

General statement

It has been customary to consider the earth as a body which is extremely hot within, with decreasing radius causing it to shrink on its center. Chamberlin's Planetesimal Hypothesis even does not dispense with a shrinking earth. It may be indeed that the earth has a decreasing radius, but it is possible also to explain the phenomena of mountain-building still more simply. Indeed, the ascertained laws of nature admit of extremely simple statement, and it seems probable that the laws of mountain-building admit also of extremely simple statement.

Imagine a globular world as large as the earth built of solid cold material, the individual portions of which fit closely into each other, the time occupied in its construction being extremely long, so as to allow of quiet settling of the closely fitting blocks into place under the action of gravity. It is assumed also that the whole mass could remain quiescent, without rock flowage or other internal movement of note, during this period of construction.

Furthermore, it may be assumed that three worlds are constructed, one of wrought-steel straps or bands carefully fitting, interlacing, and interlocking without joints or cavities, one of cubical grains of sand of various minerals, such as silica, mica, feldspar, hornblende, augite, and limestone, the grains of uniform size, closely fitting, but without bond or

[11] W. H. Hobbs: Earth evolution and its facial expression. MacMillan Co., 1921: "It is our belief, as was pointed out in a series of papers published in the Journal of Geology as long ago as 1912, that the migration of strata which become involved in the formation of arcuate mountains is exactly in the reverse direction from what Professor Suess believed it to be (c. figure 54). The mountain arcs face the sea, not because the land is thrusting itself seaward from within the continental areas behind them, but because the strata beneath these sinking sea bottoms at their front find themselves ever more slowly pinched because of their settlement, and in consequence are exerting a thrust outward against the continent."

cementing material, and one of stone blocks varying in size, shape, and strength.

On the assumption that such a construction, without internal re-arrangements being set up, has been accomplished, the globes are set freely swinging in space and are given movements of rotation on their own axes of 1,000 miles an hour.

(a) FORM OF SURFACE INDUCED IN HYPOTHETICAL ROTARY GLOBE OR EARTH

1. *Globe of steel bands.*—The weight of the steel is very great at depths exceeding 10 miles, and under such load, namely, 75 tons, approximately, to the square inch, a "flowage" of the metal would ensue if no lateral support were present. The bond, however, is so strong that there is no opportunity for steel flowage, and the mass simply seeks to avoid the pressure of the overlying mass by contracting, but this ability to contract has been assumed as practically non-existent.

2. *Globe composed of closely fitting, but non-cemented, sand grains of varying chemical composition.*—The sand is assumed to consist of equal amounts or proportions of silica, clay, mica, feldspar, limestone, and ferro-magnesian minerals.

In approaching this problem it may be advisable to draw attention to the fact that matter, apparently, has properties which may not be suspected when considered in small quantities only, but which may be appreciated readily when in enormous volume and under the influence of other still larger bodies belonging to the same group or system as that which contains the material under consideration.

Thus a student of cubes of ice in a laboratory would not be prepared, from such study only, to appreciate the action of great glaciers descending steep slopes. It is this failure to appreciate the action of ice in great masses in positions where an avenue of escape from pressure is presented to its front which has caused so many observers to doubt the efficiency of ice as a corrader. The influence of the sun, in this connection, must be borne in mind also. In a similar way the tendency of rocks to flow when under enormous pressure has not been appreciated to the full in the consideration of mountain origins. The existence of the earth's surface, or, in other words, the area or zone of negligible pressure, appears to have been overlooked in great measures. In this case, again, the action of the sun in maintaining the movements of the earth must be taken into consideration. Or, again, few students of the earth or sun in small quantities only would suspect the close relationship of biological manifestations to the solar universe as a whole.

If the sand grains under consideration should form a thin layer only, say, 100 feet or yards in thickness, there would be little or nothing remarkable to note concerning the action beyond what might be expected from laboratory experiments.

The case of the vast globe made of sand grains, tightly fitting, would be different, however.

In the mass there would be noticeable:

1. The action of gravity tending to pack the sand grains closely together.

2. The tendency for the sand to exhibit the phenomenon of "rock-flowage" at depths below the surface. This tendency would be proportional to the absence of lateral support.

3. A reaction directed toward the surface, due to this tendency to "rock-flowage."

4. The rotation of the globe on its axis.

5. The factor of time, practically limitless in duration, in the production of deformation in the sand mass.

The weight of the sand mass upon each square inch at a depth of 100 miles would be 300 tons approximately, or far more than would be necessary to cause "flowage" in the grains of quartz, feldspar, mica, and other minerals if they were not supported laterally.

In the case under consideration there is no bond between the sand particles. On the other hand, there is a very powerful reaction toward the surface, caused by the tendency of the sand to flow under its own weight, aided by the rotation of the earth and the factor of unlimited time.

If the sand were possessed of an enormously strong bond, such as that possessed by the steel bands, there would be no marked "rock flowage" except for recrystallization of the minerals and consequent slight undulations at the surface.

In the case assumed, however, there is no "bond" of strength, and there is neither load nor lateral support sufficient to prevent a strong reaction toward the surface. As time proceeds an integration of these differentiations of "flowage" is effected, and in this way the lower layers of the crust suffer deformation without fracture and tend to heap themselves toward the equator on the one hand and form undulations also following meridional directions with a tendency to oscillate at the equatorial regions on the other. These earth waves or undulations would have the appearance somewhat of waves formed in more mobile material, but they would be mutually supporting at any given moment on a subter-

ranean foundation which would be undergoing slow rock deformation or "flowage."

The depth at which this "rock flowage" would take place would be limited. Thus the tendency to "rock flowage" would decrease in efficiency—that is, in surface manifestations—below a certain depth because of the shorter perimeters of concentric shells of the globe of decreasing radius. The size of the mountains or earth undulations would depend, also, in some measure, upon the length of the globe radius. With an elongated radius, the mountains in similar material should be less, while with a decreased radius the mountains within limits should be larger, as they would not tend to sag so readily under their own weight, on the assumption of the existence of structures of comparable strength in the material of all the globes. Volcanic action would take place at certain spots where the power of "rock flowage" would be such as to cause a long-continued stretching and final disruption of the packed sand. Upon the sudden relief from the top and side pressure the sand grains would become molten and give rise both to intrusions and extrusions of igneous material.

These earth waves, like other waves, such as those of the sea, might appear to move horizontally, whereas the movements would, in reality, be undulatory, the lateral movement of the rock material being a subordinate feature during any one orogenic period.

During the relief obtained from pressure by this undulatory movement in the weaker areas, many large masses of the sand would become molten, and the cooling of these silicates would be accompanied by the growth of areas of relative stability. The process of "rock flowage" would continue, but the stronger areas would tend to rise in the form of low plateaus later, the surface material there being more "competent" than before. Fracture at the surface in these areas would be produced rather than the formation of great earth waves, their basements being in the condition of "rock flowage," but affected much more slowly than in areas of relative instability or weakness or instability. The areas of relative instability would pass outward from the more stable nuclei because of the tendency to form "hinge" areas along their margins.

3. *Globe composed of closely fitting rocks of varying chemical composition, form, and strength.*—The case is very similar to that of number 2, but the surface forms produced are extremely irregular and they depend upon the varying strength of the material acted upon.

There is a tendency for the rock blocks to "flow" even at relatively shallow depths, whereas at depths exceeding several miles the tendency

to this action is still more strongly marked within definite limits. This tendency is much more marked when the time factor is enormously increased, as in reality it becomes the summation of innumerable small momentary effects. If the rock be very strongly "bonded" above, the upward pressure of the mass, which is attempting to escape from pressure by "rock flowage," is not able to express itself at the surface. There is then a tendency to escape laterally. Escape from pressure is sought also by recrystallization with formation of denser compounds or minerals.

Generally speaking, if at any particular area the "bond" is not strong enough to prevent "rock flowage" in the subsurface masses, there is a "flowage" toward this area of relative weakness, and the surface then is forced into an undulation in the neighborhood, with or without actual rupture and production of intrusive and extrusive rock types. The surrounding areas are affected in turn at comparable depths. Under the action of world rotation, aided by an enormous time factor, the crust would be thrown into undulations or waves, which would be apparently solid and mutually supporting at any given time, the heavier portions tending to sink, at the same time buoying up the lighter portions. This condition of equilibrium is only momentary, as the material in each undulation is being continuously adjusted, with sharp local jolts or ruptures marking the limits of rock "flowage." In this continuous adjustment the portions buoyed up would be stretched toward the equator and toward the heavier (lower) portions. The motion would be undulating.

An interesting point raised is the limiting heights of the earth waves, undulations, or plateaus with depressions under various conditions. The heights would be an adjustment between the force of gravity, the fusion point of the rocks, the structural strength of the rocks, the speed of rotation of the globe, the pressure under which the rock material would tend to flow when unsupported laterally, and the factor of enormous time. The greater the force of gravity, the more fusible the material, and the greater the time factor, so also the more ephemeral the life of the ranges or earth waves and the less the height to which the ranges rise. It is conceivable thus that upon a globe of less radius than that of the earth itself, and with material of similar nature, the mountain ranges would rise higher than on the earth and exist longer without sinking under their own weight or flowing as overthrusts over their own bases.

The above is only a qualitative statement, the quantitative being a matter for later consideration.

(b) APPLICATION OF ABOVE PRINCIPLES TO THE CASE OF THE EARTH

Applying these qualitative considerations to the earth, it may perhaps be legitimate to infer that:

1. The earth's crust, at some early geological epoch, was composed of mineral masses of varying composition, "bond," and weight.

2. The strength of the upper crust was unable to withstand the long-continued reaction toward the surface occasioned by the tendency to "rock flowage" at moderate depths below the surface.

3. The structural land hollows produced thus were aggraded, while "rock flowage" was exerted outward toward the neighboring earth crests. At certain critical stages the deeply buried and unbonded sediments allowed "rock flowage" to take place within them with relative rapidity, and the sediments near the more mobile earth crests alongside were slowly overriden or overthrust. This portion of the sediments was folded closely; nevertheless the action was so well adjusted by "rock flowage" that earth crest and trough material were mutually supporting.

4. The depth at which compensation occurs is relatively slight, as is evident by a consideration of the forces of gravity and "flowage" tending to flatten the undulations and the force of gravity plus the rock bond tending to neutralize the tendency to "rock flowage" as the surface area of concentric geoid shells decreases progressively toward the earth's center.

5. At the margins of the heterogeneous crust masses the undulations are largest, as the lateral support is there greatest, causing the earth wave to seek its relief more completely in vertical movement. This action is illustrated in past and present "hinge" areas, of which the Tethyan, West and East Indian areas are famous examples, as, also, in all probability, the areas now occupied by the Ural and Appalachian Mountains and the American Cordillera, together with other areas of mountains still more ancient.

Taylor[12] and Wegener[13] see mountains as incidents in wide driftings of continents from ancient moorings.

One great difficulty in the way of acceptation without qualification of this fertile conception is the existence of horizontal sediments over large areas, even among rocks of great geological age. The movements hypothecated demand a substratum either molten and very mobile or one allowing very slow movement by "rock flowage." In the former case

[12] F. B. Taylor: Movement of continental masses under action of tidal forces. Pan American Geologist, vol. xliii, February, 1925.

[13] A. Wegener: Die Entstehung der Kontinente und Ozeane. Braunschweig, 1915.

there would be a tendency for masses to be engulfed as time progressed; in the latter case the crust would yield differentially, and horizontal bedding could not exist during the passage of long geological periods.

Daly[14] conceives a slow sliding of whole continental blocks over a substratum of volcanic glass, forming mountain chains near its margins, where resistance to the slow sliding is opposed. In this hypothesis great sections of the earth's crust which have been heaved and tilted slowly out of a stable position are conceived as migrating gradually in the directions of their slopes.

It does appear that there is a general dip of the old land surfaces toward the ocean deeps,[15] and this would imply a movement, under gravity, toward the oceans. This conception of Daly's may be expected to be of great assistance in the discussions on mountain origins.

Keith,[16] with others, assigns an extremely important part to igneous intrusions in mountain-building.

While appreciating the fact that igneous intrusions are extremely important agencies during mountain-building, especially as so splendidly brought out in Keith's paper on the Appalachian Mountains, cited above, it would seem that mountains and igneous rocks may be conceived as arising alike from the "rock flowage" determined by development of avenues of escape from pressure.

It is that in earlier discussions the relation between "rock flowage" and the surface needed rather more special attention. It is difficult to conceive[17] the possibility of "rock flowage" in a solid earth without a surface of negligible pressure.

The marked "rock flowage," with consequent rock melting (igneous action), which has been so common in the earth waves of geological time, has always tended to increasing stability of the crust, and "hinge" areas thus would pass outward, with tendency to increasing stability of earth wave areas.

Despite this tendency, however, to growing stability of continental areas, the "rock flowage" affects the whole continental areas, giving a tendency to flowage or gravitation toward the lower (ocean) blocks and toward the equator, setting up thus a stretching or "rock flowage" out-

[14] R. A. Daly: Quoted from abstract in Science, n. s., vol. lxi, no. 1583, 1925, p. x.

[15] E. C. Andrews: Geographical distribution of ore deposits in Australia. Economic Geology, vol. xviii, 1923, pp. 1-25.

[16] Arthur Keith: Outlines of Appalachian structure. Bull. Geol. Soc. Am., vol. 34, 1923, pp. 309-380.

[17] E. C. Andrews: Contribution to the hypothesis of mountain formation. Bull. Geol Soc. Am., vol. 34, 1923, pp. 398-399.

ward with wrinkling or undulations at obstacles and at "hinges." Such principle would explain the action of the suboceanic mass of the Pacific, nevertheless the stretching, without rupture, from the ancient nuclei toward the outlying earth troughs, such as the continental plains and the ocean basins.

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REYNOSA FORMATION IN LOWER RIO GRANDE REGION, TEXAS[1]

BY ARTHUR C. TROWBRIDGE

(Read before the Society December 28, 1924)

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PREVIOUS WORK

In 1890 Penrose,[2] as a result of his trip down the Rio Grande with Dumble in 1889, described a deposit of limestone containing pebbles and cobbles, under the name "Reynosa limestone," from the town of Reynosa, Tamaulipas, Mexico, across the Rio Grande from Hidalgo, Texas. At Reynosa the rocks unconformably overlie what was then called the Fayette sands, now known to include strata of upper Eocene, Oligocene, and Miocene age. Penrose found Recent shells embedded in the surface of the exposure and, thinking the formation was Recent, included it in his "post-Tertiary formations."

In 1891 Hill[3] described patchy remnants of a formation that consisted of gravel cemented by a calcareous matrix, and that occupied terraces 400 to 1,000 feet above the Rio Grande, in Uvalde and adjacent counties in Texas, and called it the "Uvalde formation," for the town of Uvalde,

[1] Manuscript received by the Secretary of the Society September 2, 1925.
Published by permission of the Director of the United States Geological Survey.

[2] R. A. F. Penrose, Jr.: Report of Geology for eastern Texas. Texas Geol. Survey, First Ann. Rept., 1890, pp. 57, 58, 63.

[3] R. T. Hill: Notes on the geology of the southwest. Am. Geologist, vol. 7, 1891, pp. 366-370.

in Uvalde County, and in 1898 Hill and Vaughan[4] interpreted the "Uvalde" formation as residual material washed out from the Edwards Plateau in late Tertiary time and deposited in fan-shaped areas on the downthrown side of the Balcones fault, which separates the Edwards Plateau from the Rio Grande plain, on which the gravels and conglomerates occur.

In 1894 Dumble[5] applied the name Reynosa "Division" to a thick and continuous formation of limestone and conglomerate between the Rio Grande and Nueces River and made the "Reynosa limestone" of Penrose the top member of his Reynosa "Division." This correlation of Dumble's has been questioned by Deussen.[6]

In 1923 the writer[7] correlated the Reynosa of Penrose and Dumble with the "Uvalde" of Hill and Vaughan and adopted the term Reynosa formation.

Distribution

Figure 1 shows the Reynosa cropping out as a continuous formation in a belt 20 to 35 miles wide in Webb, Jim Hogg, Starr, and Hidalgo counties, and Deussen[8] has mapped a continuation of this belt of outcrop northward and eastward to Brazos River. Chiefly because of its porosity, and hence its superior resistance to erosion as compared with underlying clays, the formation gives rise to a cuesta, the eastward slope of which corresponds with the eastward dip of the formation. The steep west face of the cuesta is known as the Bordas scarp. In addition, there are numerous patches of gravel capping the higher hills west and north of the main belt of outcrop, as shown in Figure 1.

Stratigraphic Relations

Where the formation is continuous between Rio Grande and Nueces rivers it lies upon the Eocene Frio clay and on the Miocene Oakville sandstone, with a notable erosional and structural unconformity between, the Pliocene Lapara and Lagarto formations being missing or overlapped; and near the Gulf coast the Reynosa formation is overlain un-

[4] R. T. Hill and T. W. Vaughan: Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas. U. S. Geol. Survey, Eighteenth Ann. Rept., pt. 2, 1898, pp. 244-247, 254-255.

[5] E. T. Dumble: The Cenozoic deposits of Texas. Journal of Geology, vol. 2, 1894, p. 560.

[6] Alexander Deussen: Geology of the coastal plain of Texas west of Brazos River. U. S. Geol. Survey Prof. Paper 126, 1924, p. 102.

[7] A. C. Trowbridge: A geologic reconnaissance in the Gulf coastal plain of Texas near the Rio Grande. U. S. Geol. Survey Prof. Paper 131, 1923, p. 99.

[8] Alexander Deussen: Ibid., plate viii.

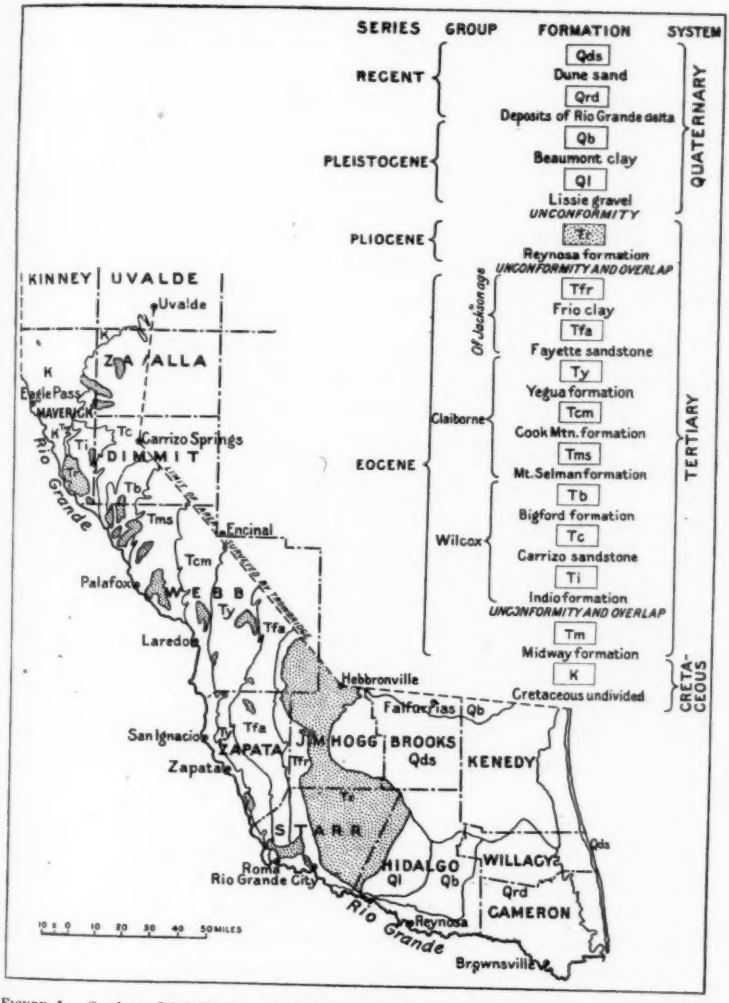

FIGURE 1.—*Surface Distribution of the Reynosa Formation in the Lower Rio Grande Region*

Adapted from Trowbridge.[8]

[8] A. C. Trowbridge: Ibid., plate xxviii.

conformably by the Lissie gravel, from which the remains of Pleistocene horses have been taken.

On the landward side of the belt of continuous outcrop the formation, as isolated patches, lies unconformably by overlap on all Eocene formations and in places overlaps the Eocene and lies on the Cretaceous (figure 1).

Age

Except for the remains of Recent land snails, crayfish, jackrabbits, and a few other animals which have become embedded in the surface as the limestone has been dissolved and reprecipitated, and except for fossils originally deposited in the formations from which the gravel was derived, no fossils have been found in the Reynosa formation, so that its precise age cannot be determined; but its stratigraphic position, unconformably above the Miocene and above the early Pliocene and unconformably below the Pleistocene, indicates late Tertiary or early Pleistocene age, and it is tentatively assigned to the Pliocene. These sediments were included in the "Lafayette" of McGee and are of about the same age as the Pliocene Citronelle formation of east Texas, Louisiana, Mississippi, and Alabama.[16]

Lithology

The Reynosa formation is an intricate mixture of gravel cemented by lime carbonate, uncemented gravel, limestone in which are embedded pebbles and cobbles, almost gravelless limestone, sand, sandstone, gravelly sand, and a relatively small amount of clay.

The pebbles and cobbles consist of chert, limestone, vein quartz, and igneous rocks of various sorts. Where the gravel or conglomerate overlies the Fayette, Frio and Oakville formations it includes petrified wood. Most of the pebbles and cobbles are well shaped by abrasion, many of them are highly polished, and some show markings made by hard impact during transportation. The gravel deposits are roughly sorted into lenses and pockets of different textural grades (fig. 2).

The limestone is gray and sandy and weathers into rough, irregular surfaces, due to irregular concretions and impurities. In places it has surficially a tuffaceous appearance. Its basins, rims, terraces, channels, and concentric banding are suggestive of deposition by springs. Patches south of Espejo Ranch, in north-central Webb County, and at Carrizo

[16] G. C. Matson and E. W. Berry: The Pliocene Citronelle formation of the Gulf coastal plain and its flora. U. S. Geol. Survey Prof. Paper 98, pp. 167-204.

Springs are clearly spring deposits, but these are not typical, for they contain little or no gravel.

The sands and sandstones are gray or brown or red and almost universally weather into a dark-red sand. The grains are quartz coated with red iron oxide, but in places where this red coating has been worn off by the wind the sand is gray or even white.

The few clays are generally sandy, but some are almost fat.

The surficial material derived from the Reynosa is typically deep-red, pink, or gray sand, through which white or gray limestone projects at many places.

Laboratory analysis of a number of samples of limestone from the Reynosa formation shows that 70 per cent to 90 per cent is $CaCO_3$, with

FIGURE 2.—*Reynosa Gravel*

Location is on the International and Great Northern Railway at Greens, Webb County.

an average of 78 per cent; that 6.4 per cent to 20.4 per cent is quartz, orthoclase, plagioclase, and minute quantities of heavy minerals, with an average of 13.3 per cent, and that 2.0 per cent to 17.6 per cent is fluffy or flaky white or buff clay, with an average of 12.1 per cent. Some of the percentages given for $CaCO_3$ include small amounts of manganite. The colors include gray, white, cream, and tan. A typical mechanical analysis of the insoluble residue is given in figure 3, which shows a textural range from medium sand to clay, with a double maximum in the fine sand and clay grades. In all samples a large proportion of the grains in grades

above 1/16 millimeters are rounded and some of the grains are well rounded and frosted, indicating eolian action. Some of the samples have a roughly radial and concentric structure, in which the laminæ curve and govern the distribution of the grains, and others have horizontal laminæ with the sand grains oriented and the $CaCO_3$ evenly distributed.

Thickness

The thickness of the formation near the Rio Grande is not definitely known. The patchy deposits west of the Bordas do not exceed 30 feet in thickness, but at the east border of the main belt of outcrop the formation

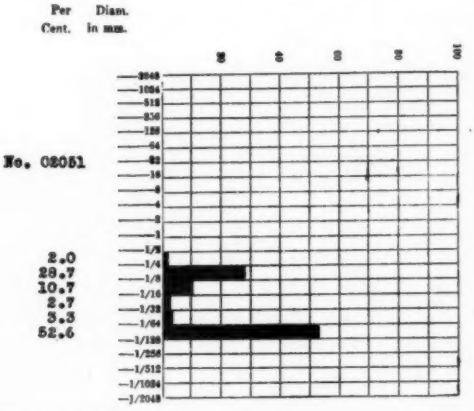

Figure 3.—*Mechanical Analysis of Residues from Sample Number 02051*

This sample is from the Bordas scarp, 10 miles southeast of Aquilares. The analysis was made after dissolving 70 per cent of its contents in dilute acid.

may be 500 feet thick or more, and farther north it is reported by Deussen[11] to vary in thickness from 200 to 1,505 feet.

Origin and History Recorded

Such an unusual mixture of limestone with clastic sediment, including coarse gravel and clay, the whole making up a formation of such thickness and continuity, constitutes a problem in geological genetics of more than usual interest and importance—a problem upon which it is hoped the field and laboratory work on which this paper is based casts light.

After the Oakville sandstone was deposited, and probably after the

[11] Alexander Deussen: Ibid., p. 103.

formation of the Lapara sand and Lagarto clay, the coastal plain of southwest Texas appears to have been slightly elevated, tilted, and eroded, so that a peneplain was formed, beveling all formations and doubtless extending northward and westward across the Edwards Plateau toward and perhaps to the Cordilleran Mountains of west Texas and New Mexico. On this low-lying surface the products of weathering accumulated. The cherty Cretaceous limestones of the Edwards Plateau gave rise to calcareous, agrillaceous, and arenaceous residual soils and to fragments of chert which could not be dissolved and were left at the surface. The higher surfaces west of the Edwards Plateau were probably subdued and likewise covered by residual materials, such as clay, sand, and fragments of vein quartz.

The Tertiary sediments of the coastal plain were similarly weathered to form surficial residual soils consisting of clay, sand, silicified wood, et cetera. On this whole surface such residual materials probably accumulated to considerable thickness.

At some time late in the Tertiary, probably in the Pliocene, this condition was changed by a diastrophic disturbance in which the Balcones fault was formed, the Edwards Plateau and perhaps the plateaus and mountains farther west were upthrown and elevated, and the coastal plain was downthrown and left as a low and relatively reliefless plain, extending from the foot of the Balcones scarp to the Gulf coast.

The elevation of the surfaces west of the escarpment, by increasing the declivity and perhaps by interference with winds giving rise to increased precipitation, caused the rejuvenation of streams, which were thus enabled to remove large quantities of the accumulated residuum, even including the fragments of chert and other insoluble residues. Some of the streams in time penetrated the surficial materials and eroded their valleys into the unweathered rocks below.

This elevation also increased the ground-water circulation and gave rise to gulfward-moving water beneath the surface, carrying large quantities of calcium bicarbonate and other soluble salts in solution.

The materials thus removed from the elevated surface to the west were deposited on the relatively depressed plain south and east of the Balcones scarp. The shallow valleys were filled and the streams wandered over the general surface, spreading a more or less continuous sheet of sediment. In general, the finer materials were carried on to the Gulf and the coarser ones were left on the surface to make up the Reynosa gravels. Thus a sort of piedmont plain was formed topographically and a sort of compound fan lithologically.

The larger and more vigorous streams, such as the Rio Grande, carried and deposited the coarser gravels. Most of the pebbles and cobbles of the gravels and conglomerates came from the Edwards Plateau, but the Rio Grande brought vein quartz and igneous rocks from the western mountains across the plateau, to be deposited on the coastal plain with the rest.

The limestone of the Reynosa was contributed mainly by ground water and perhaps to some extent by the streams. The ground water, rich in dissolved calcium carbonate, coming from the elevated western area with invigorated circulation, stood high in the pores and close to the low surface of the eastern plain. Although rainfall was at least fairly abundant in the high plateaus to the west, the coastal plain was arid or semiarid, then as now, and evaporation caused the precipitation of the calcium carbonate to form the limestone. Some of the precipitation took place in the pores of the gravel near the surface, as the surface was built up by the deposition of the gravel. Some of the limestone, such as that near Hebbronville and elsewhere in the main belt of outcrop, and that at Carrizo Springs and at Los dos Hermanos, in Webb County, was precipitated at the surface from springs, forming cones and terraces where the springs issued, and deposits of bolson and alkali-flat types in shallow basins into which the spring water flowed and evaporated. Perhaps, also, some of the stream water flowed into sloughs, bayous, resacas and lagoons, and into shallow flats, where it was evaporated and deposited its dissloved salts. The laboratory analyses, which show rounded and frosted sand grains embedded in the limestone, demonstrate that sand and dust were shifted about by the wind and blown into these surface waters to be inclosed in the tuffaceous deposits.

The faulting which caused and conditioned the deposition of the Reynosa was doubtless renewed from time to time, as deposition on the coastal plain progressed, and that portion of the plain near the fault line or zone was probably dragged up somewhat periodically, resulting in partial or complete removal, or at least a thinning, of the surficial sediment there and a thickening of the formation toward the coast. Thus the Reynosa came to be thicker east of the Bordas scarp than west of it.

After the deposition of the Reynosa its landward margin, where the sediments were thin, was eroded until only remnants remain on the higher portions of the surface, and the thicker deposit nearer the coast remains as a continuous formation dipping below the Pleistocene and Recent coastal clays.

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GROUND-WATER PROBLEMS ON THE BARRIER BEACHES OF NEW JERSEY[1]

BY DAVID G. THOMPSON[2]

(*Read before the Society December* 29, 1925)

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INTRODUCTION

Several of the important resorts of the New Jersey shore, from Atlantic City southwestward, are situated on barrier beaches which are separated from the mainland by open bays or tidal marshes, as shown in figures 1 and 2. The water supply for these resorts is largely obtained from deep drilled wells located on the barrier beaches. An average of about 5,000,000 gallons daily is pumped from wells in Atlantic City and about 3,000,000 in near-by cities. During the past 30 years the head on the water in the principal water-bearing horizon has dropped more than 80 feet. In view of this fact, it becomes important to determine, so far as possible, the ultimate safe yield of the formation.

This paper presents some of the results of a study of ground-water conditions in the Atlantic City region undertaken jointly by the New Jersey Department of Conservation and Development and the U. S. Geological Survey to obtain information upon this problem. Since the first wells were drilled in the region, nearly 40 years ago, a wealth of logs and sand samples have been obtained. These have been critically studied by Dr. M. W. Twitchell, Assistant State Geologist, and the

[1] Manuscript received by the Secretary of the Society March 1, 1926.
Published by permission of the Director of the U. S. Geological Survey and the Director of the New Jersey Department of Conservation and Development.
[2] Introduced by Kirk Bryan.

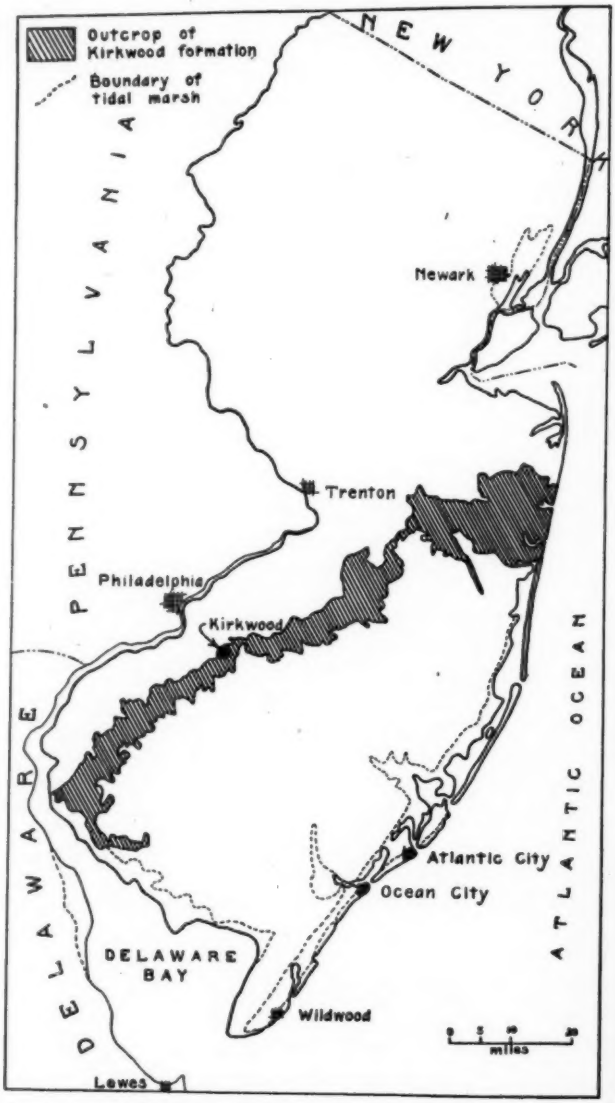


FIGURE 1.—*Outcrop of Kirkwood Formation and Location of Resorts using Water from the Atlantic City 800-foot Sand*

stratigraphy of the region is well in hand. Accordingly the writer's work has related principally to the quantitative phases of the problem.

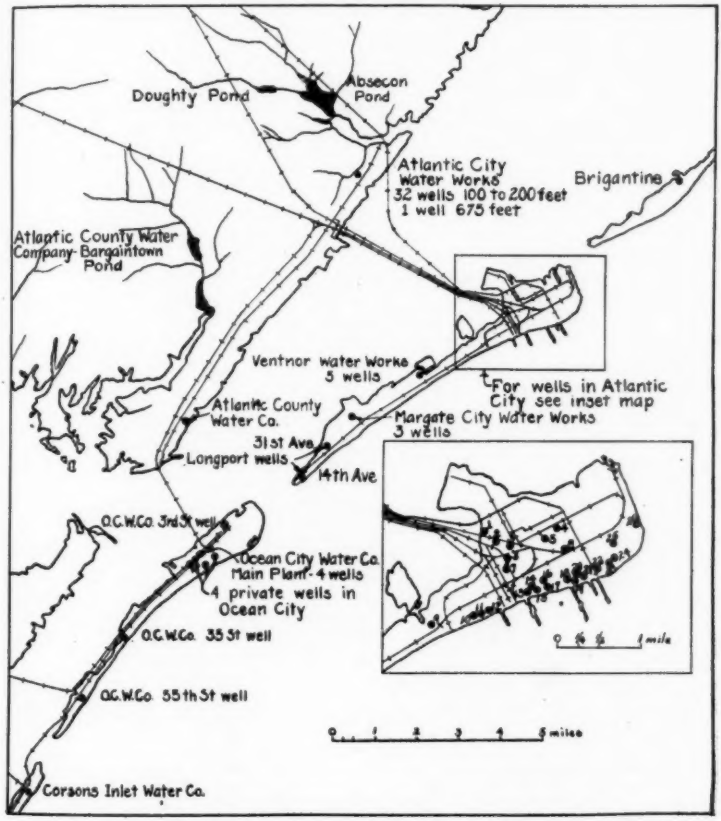

Doughty Pond
Absecon Pond
Atlantic City Water Works
32 wells 100 to 200 feet
1 well 675 feet
Brigantine
Atlantic County Water Company Bargaintown Pond
Ventnor Water Works 3 wells
For wells in Atlantic City see inset map
Atlantic County Water Co.
Margate City Water Works 3 wells
31st Ave.
Longport wells
14th Ave.
O.C.W.Co. 3rd St well
Ocean City Water Co. Main Plant-4 wells
4 private wells in Ocean City
O.C.W.Co. 35 St well
O.C.W.Co. 55th St well
Corsons Inlet Water Co.
0 1 2 3 4 5 miles
0 ¼ ½ 1 mile

FIGURE 2.—*Location of Wells in Atlantic City Region drawing on the 800-foot Sand*

GEOLOGIC CONDITIONS

The significant geologic features are shown in figure 3, a cross-section along a line between Philadelphia and Atlantic City, approximately along the dip of the beds. This section is based largely on data furnished by Dr. Twitchell. Most of the wells on the beaches from Atlantic City southwestward draw from an extensive sand bed, 80 feet thick, which lies at a depth of about 800 feet at Atlantic City and is commonly called

the 800-foot sand. The depth to the formation increases southwestward along the coast, being about 900 feet at Wildwood.

At Atlantic City the 800-foot sand is the only formation to a depth of 2,300 feet that yields a large supply of fresh water. On the mainland water-bearing sands above a depth of 250 feet yield good water, but in Atlantic City these formations contain only brackish or salty water. Salt water is effectively shut out from the 800-foot sand by a 300-foot layer of diatomaceous clay, as is shown by the fact that in the city the water contains only 6 to 11 parts per million of chloride. Several wells have yielded salt water, but it has been proved in each instance that the salt water came through defective casing from the overlying formations, for when the casing was repaired or a new well was drilled near-by the well furnished fresh water of normal low chloride content.

The 800-foot sand and the overlying clay are believed to be part of the Kirkwood formation, of Miocene age, which outcrops about 45 miles northwest of Atlantic City (see figure 1). It is not certain, however, whether the sand bed is present in the outcrop area or is buried by later sediments which partly overlap the formation. Certain water-bearing beds which yield large quantities of water near Camden, notably the Raritan formation of Cretaceous age, were not reached in a well 2,300 feet deep at Atlantic City, but they may be present at a greater depth.

Effects of Pumping

When, about the year 1894, the first wells were drilled to the 800-foot sand, the water flowed and the level of no flow or static head stood 20 or 25 feet above sealevel. Since then, as pumping has increased, the head has dropped gradually and in the summer of 1925 in Atlantic City the water stood about 65 feet below sealevel, or at least 80 feet below the original level. As shown by the upper profile in figure 4, the static head has declined for many miles along the shore, but it is lowest in Atlantic City, where the quantity of water pumped is greatest. The area in which the head has declined extends at least some 8 or 10 miles inland and doubtless nearly as far out beneath the ocean (see figure 4, B).

To obtain information as to the effect of pumping, the movement of the water-level in a well at Longport, about 5 miles southwest of Atlantic City, has been recorded for more than a year by an automatic gage. The records show a semi-diurnal fluctuation that is obviously due to the tide. The daily range between high and low water in the well varies from about 1 to 3 feet at different times of the month and is a little more than 50 per cent of the range of the tide.

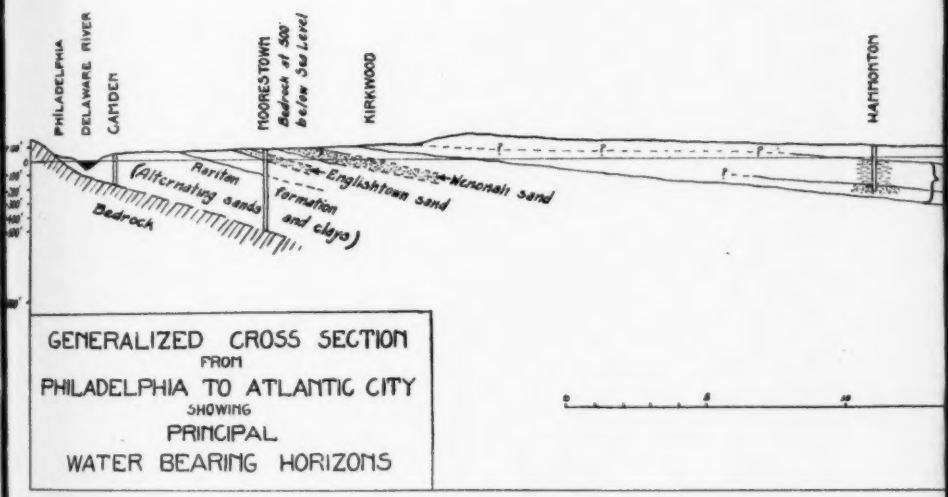
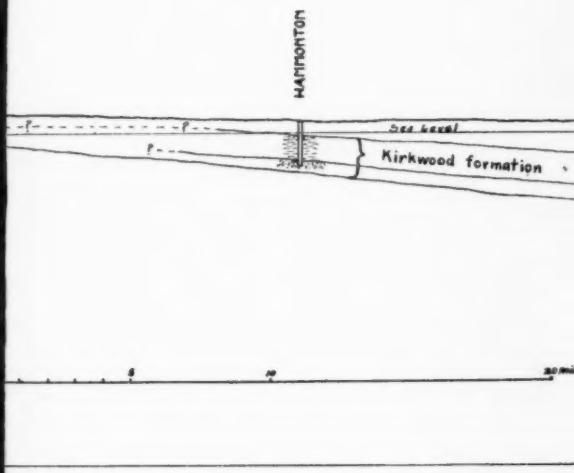
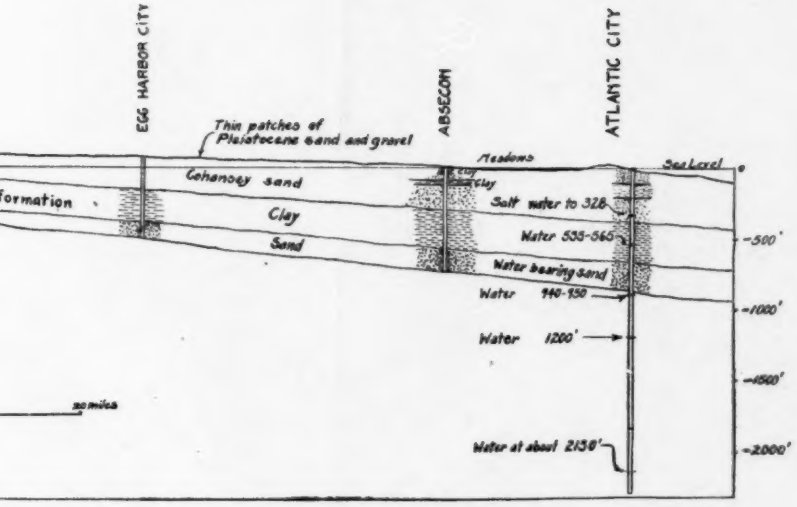


FIGURE 3.—*Generalized geologic Cross-section*



URE 3.—*Generalized geologic Cross-section from Philadelphia to A*



elphia to Atlantic City

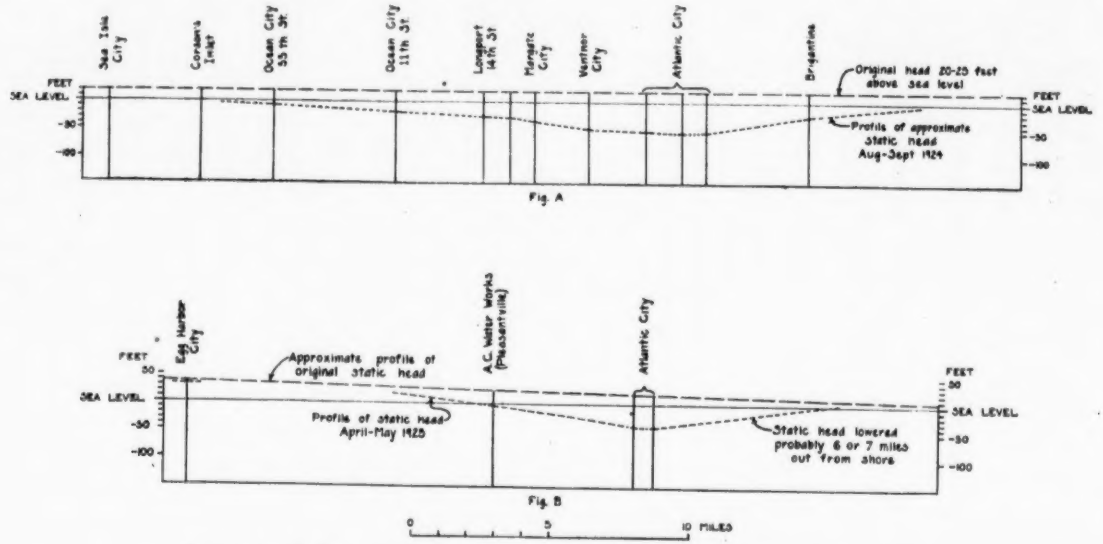


FIGURE 4.—*Profiles showing static Head on the 800-foot Sand in the Atlantic City Region*

A, profile parallel to the coast; B, profile at right angles to the coast.

To determine whether the water-level in the well fluctuates from other causes, the tidal effect has been eliminated, so far as possible, by computing for each day the average of the two high and two low water levels—in other words, the daily mean water-level. The resulting line is shown in figure 5. This graph also shows the pumpage, generalized to eliminate daily fluctuations, at Ventnor, a near-by city, which obtains its water supply from the 800-foot sand.

Effects of Future Increase in Pumping

Neglecting these day-to-day fluctuations, a major movement is found that extends through the entire year. As the pumpage increases in summer, the water-level falls, and as it decreases after the resort season closes in September the water-level rises. The drop in the water-level is not due merely to the summer increase in pumping at near-by Ventnor, but also to the large draft on wells at other neighboring cities where the use of water, as at Ventnor, is greatest in the summer season. It will be noted that the water-level in the winter of 1924-1925 was lower than the first measurement obtained in June, 1924, and therefore presumably lower than in the winter of 1923-1924, and that the lowest level reached in the summer of 1925 was nearly 10 feet lower than that of the preceding summer. During the summer of 1925 the average daily pumpage was about the same as during the previous summer, but, as shown by figure 5, the period of heavy draft was more prolonged. The decline in the head lags behind the increase in pumpage. As a result, because of the longer period of heavy draft in 1925, the head had an opportunity to decline further before it approached a condition of stability. From these facts and a consideration of the principles of hydraulics it is concluded that as the draft on the 800-foot sand increases there will be a further lowering of the head. The probable extent of this lowering has not yet been determined, but it becomes evident that an improtant factor limiting the ultimate yield of the formation will be the depth from which the water can be economically pumped.

Danger of Salt-water Contamination

The static head on the 800-foot sand in the Atlantic City region has been below sealevel for many years. Considering the location of the wells on the beaches within a few hundred feet of the ocean, it is not surprising that salt water has not been drawn into the wells? The writer does not know of any similar situation where heavy pumping has not

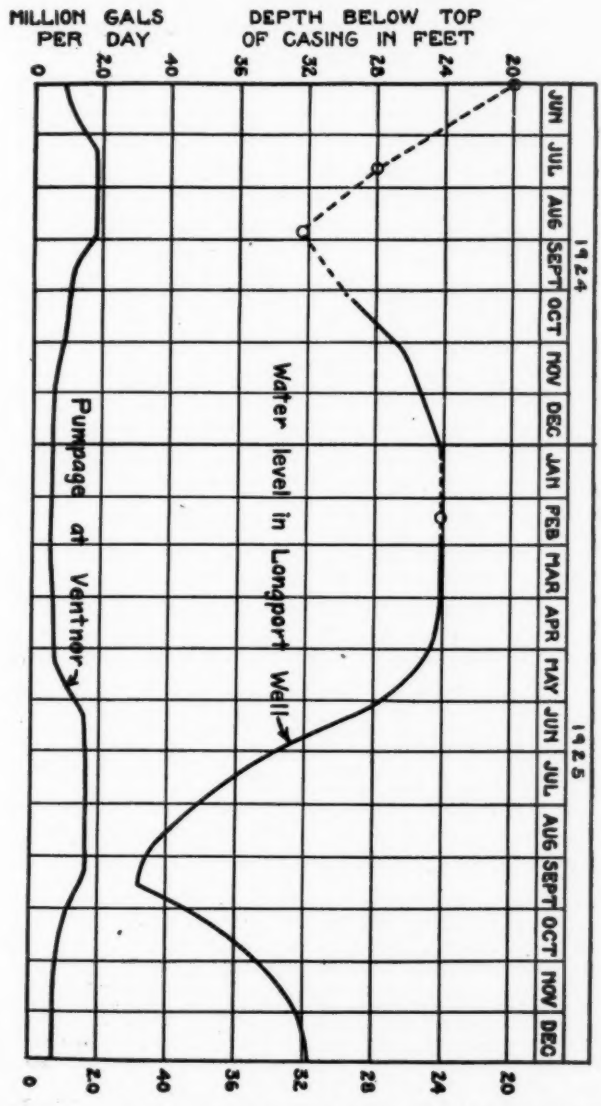


FIGURE 5.—*Water Level in observation Well at Longport and Pumpage at Ventnor*

resulted in salt-water contamination, even in localities where the conditions appear to be less conducive to contamination than at Atlantic City. Thus, in certain of the well fields of the New York Board of Water Supply on Long Island, salt water was drawn in, even though the wells were farther from the ocean and the pumping head was at most only a few feet below sealevel.[3]

It appears that an important factor hindering contamination of the 800-foot sand at Atlantic City is the presence of the overlying 300 feet of impervious clay, which prevents the direct access of ocean water. A question of moment, then, is whether the sand contains only fresh water throughout its entire extent or whether at some place it carries salt water which may be drawn into the wells at some future time. In view of the practical importance of the problem, the writer has been led to speculate on conditions beneath the ocean with the following results:

The 800-foot sand is a marine formation and must once have contained sea water. The presence of fresh water can be explained only by movement of the original salt water down the dip and therefore seaward to a suboceanic outlet. Such movement is indicated by the fairly well substantiated fact that when the horizon was first tapped by wells there was a definite hydraulic gradient seaward of about 1 foot per mile. If the dip of the formation at Atlantic City, about 25 feet per mile, continues offshore, its outcrop would be at the edge of the continental shelf about 90 miles out and at a depth of about 3,000 feet, as shown in figure 6, A. If the formation is filled with fresh water to the outcrop, the weight of the salt water in contact with it at the outlet, assuming an average density of 1.025, would create a head sufficient to cause the fresh water to rise at least 75 feet above sealevel.[4] It must be remembered that this head would exist at the outcrop at the edge of the continental shelf. It would be fully as great at Atlantic City, and if the fresh water were moving oceanward it would necessarily be even greater. Thus, if the hydraulic gradient required for movement of the water were only

[3] W. E. Spear: Long Island sources of an additional supply of water for the city of New York, New York Board of Water Supply, vol. 1, pp. 145-149, 1912. Also John S. Brown: A study of coastal ground water with special reference to Connecticut. U. S. Geol. Survey Water Supply Paper 537, pp. 45-48, 1925.

[4] According to H. B. Bigelow (Exploration of the coastal water between Nova Scotia and Chesapeake Bay, July and August, 1913, by the U. S. Fisheries schooner *Grampus*. Bull. Mus. Compar. Zool., Harvard Coll., vol. IIx, no. 4, September, 1915, fig. 59, p. 219), the ocean water in the great abyss beyond the continental shelf abreast of Barnegat, New Jersey, has a density of about 1.023 near the surface, which increases to 1.025 at a depth of about 120 feet and of 1.029 at a depth of about 1,500 feet. The average density of the column of water to a depth of 3,000 feet is therefore somewhat greater than 1.025, so that the figure given above is conservative.

1 foot per mile, the static head at Atlantic City would have to be about 165 feet above sealevel. When the first wells were drilled, no such high head as this existed, nor even as high as 75 feet. It is therefore evident

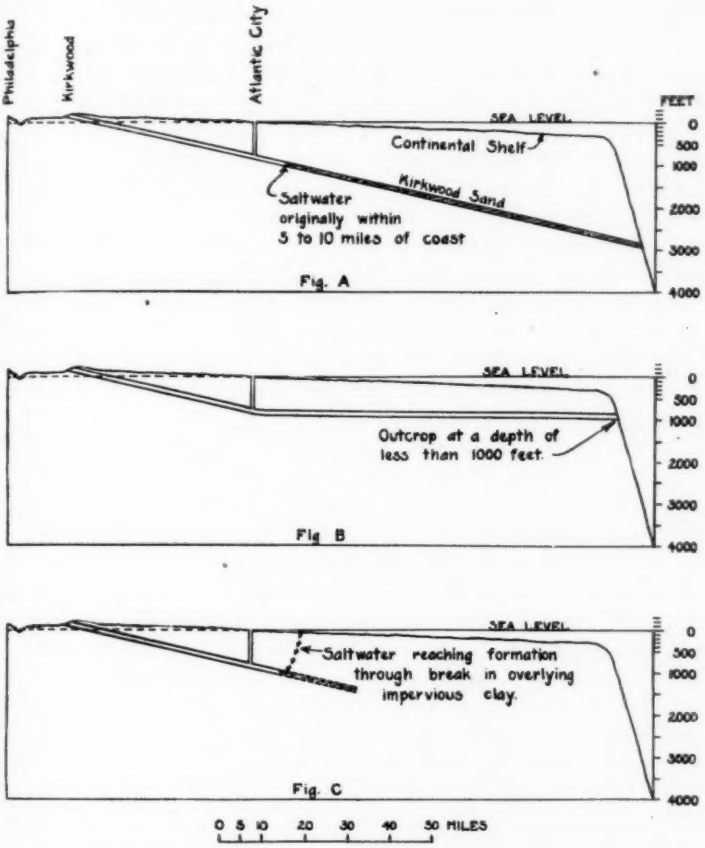


FIGURE 6.—*Diagrams showing possible alternative Conditions which would account for a Head of 25 Feet on the 800-foot Sand at Atlantic City*

that the 800-foot sand does not contain fresh water to a depth of 3,000 feet.

The original static head of 20 to 25 feet at Atlantic City is equivalent to a column of salt water only 800 to 1,000 feet high and having a den-

sity of 1.025. From the facts stated, the following alternative conclusions arise:

1. If the formation does outcrop at the edge of the continental shelf at a depth of 3,000 feet, it must be filled with salt water back to a point where its depth is less than 1,000 feet, as shown in figure 6, A.

2. The dip of the formation offshore may be much less than 25 feet per mile and the outcrop may be at a depth of less than 1,000 feet, as shown in figure 6, B. However, it seems that the head necessary to create flow to the outcrop—and some flow seems to have existed before pumping began—would be so great that the head at Atlantic City would have been considerably more than 25 feet. This conclusion, therefore, does not seem in harmony with the actual conditions.

3. The salt water creating the head on the formation may gain access to it much nearer shore than the edge of the continental shelf through relatively permeable overlying materials, as in figure 6, C. It will be noted in figure 1 that the Kirkwood formation is beveled off beneath the ocean along the coast some 50 miles north of Atlantic City and in the lower part of Delaware River. Doubtless salt water has gained access to the formation, at least in the former locality.

In the above discussion no consideration has been given to several questions of a strictly stratigraphic nature, such as the likelihood that the 800-foot sand extends to the edge of the continental shelf, some 135 miles from its outcrop on the land; or the probability that the thick clay bed is continuous over the sand and wholly effective in preventing salt water from reaching the sand except at the edge of the continental shelf; or of the possibility that some unsuspected structural condition might give salt water access to the formation at a depth of less than 1,000 feet to the formation. Regardless of the reasonableness of any of these possibilities, there seems to be no escape from the conclusion, based on hydraulic data, that the zone of diffusion between salt and fresh water is at a depth of less than 1,000 feet below sealevel.

If the dip of the formation offshore is 25 feet per mile, as at Atlantic City, the diffusion zone must be less than 8 miles out, and, if allowance is made for loss of head due to flow, probably several miles less. At Wildwood the formation lies at a depth of about 900 feet and conditions there should be somewhat comparable to those about 4 miles offshore at Atlantic City. If the salt water is within a few miles of Atlantic City, the water in the Wildwood region may be expected to show a somewhat greater chloride content. The following table gives the range of chloride in water from wells drawing on the 800-foot sand as determined by

analyses made at frequent intervals during the past 15 years. The localities are arranged in order from north to south.

Range in Chloride Content of Water from Wells to 800-foot Sand

(From Analyses by N. J. State Department of Health, 1910-1925, and U. S. Geological Survey, 1924-1925)

	Depth of wells	Chloride, parts per million	
		Minimum	Maximum
Absecon (mainland)	675	3	6
Atlantic City	800-840	6	11
Ventnor	825	5	10
Margate	815	3.5	10
Longport	850	5.5	11
Ocean City	840	6.5	12.5
Corson's Inlet	856	14	18
Sea Isle City	863-875	15	18
Avalon	925-935	30	36
Stone Harbor	890	?	49
Wildwood	931	?	?

No early analyses are available for Wildwood, but recent analyses from two wells, one of them completed in September, 1925, show a chloride content of 181 and 370 parts per million respectively. However, until further observations have been made, it cannot be determined whether this high chloride is due to salt water being drawn in from the seaward part of the formation or whether it comes from higher formations through defective casing.[4a]

Disregarding the Wildwood analyses, the table indicates an increase in chloride content of the water from north to south. The maximum figures have usually been obtained in analyses in later years, and a slight increase in each locality is thus indicated. Farther south, in a well at Lewes, Delaware, 25 miles southwest of Wildwood, the water from a formation at a depth of 887 to 931 feet, which is believed to be the same as the 800-foot sand at Atlantic City, was so salty that it was not used.[5]

The differences in chloride content and increase in the past 15 years are small, but they assume greater significance when it is understood, as has been shown by experience elsewhere, that the zone of diffusion between fresh water and practically pure sea water may be only a few feet

[4a] Tests made since the above was in type indicate that the high chloride contents noted, 181 to 338 parts per million, are not due to leakage from other horizons through defective casing, but represent the normal content of the 800-foot sand at Wildwood.

[5] Lewis Woolman: Artesian and other wells in New Jersey. Annual Report of the State Geologist for 1898. N. J. Geol. Survey, p. 83.

to a few hundred feet in width, and that the change from fresh water to salt water in a field that is pumped heavily may occur within a very short time. For example, on the Holland coast the diffusion zone has been found to be only 60 to 100 feet wide.[6] At the Shetucket well field of the New York Board of Water Supply the chloride increased from 45 to 100 parts per million in a little more than a year and in 5 years it increased to 500 parts per million, although the pumpage had been greatly decreased.[7] A case is recorded of a well at Eastbourne, England, in which the chloride rose to some 2,000 parts per million in 12 months.[8]

In view of the evidence presented, it seems entirely possible that salt water may even now be only a few thousand feet from the coast in the Wildwood region. If similar conditions exist 4 or 5 miles offshore at Atlantic City, the salt water may be well within the area in which the head has already been lowered, which, as shown above, probably extends some 7 miles seaward, and consequently the salt water may be moving toward the Atlantic City wells. If this is true, it is only a question as to the time required for the salt water to reach the wells. The landward movement of the salt water would not begin until the area influenced by pumping had reached the diffusion zone some years after the first wells were used. At first the landward movement of salt water would be slow, and rough computations show that even under the present pumping draft it probably would require at least some tens of years for the water to move 4 or 5 miles; but as the total water pumped from the horizon promises to increase each year the rate of movement will be accelerated. It appears, therefore, that the danger of salt-water contamination may become fully as important a controlling factor as the economic pumping lift in determining the ultimate safe yield of the 800-foot sand at Atlantic City.

[6] John S. Brown: Op. cit., p. 36.

[7] W. E. Spear: Op. cit., pp. 145-147; and J. S. Brown: Op. cit., p. 47.

[8] W. P. Mason: Damage to wells by sea water. Jour. Am. Water Works Assoc., vol. 8, no. 1, discussion by William Gore, p. 71, January, 1921.

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DEVONIAN VOLCANIC ROCKS NEAR DALHOUSIE, NEW BRUNSWICK[1]

BY W. V. HOWARD[2]

(Read before the Geological Society December 28, 1925)

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INTRODUCTION

The area described in this paper lies between the towns of Dalhousie and Campbellton, on the south shore of the Restigouche River, and in the extreme northern portion of the Province of New Brunswick, Canada. The attention of geologists has been called to this region for some years because of the presence of a rich Helderbergian fauna in a sedimentary series, interbedded with a number of lava flows and intrusive sheets, about one mile east of Dalhousie. Since previous descriptions of this locality did not seem to afford a satisfactory explanation of the nature of the igneous rocks, the writer spent the summer of 1923, under

[1] Manuscript received by the Secretary of the Society March 24, 1926.
Published by permission of the Director, Geological Survey of Canada.
[2] Introduced by George H. Chadwick.

the auspices of the Honorary Advisory Council for Scientific and Industrial Research, in an endeavor to explain their occurrence.

Previous Work

With the exception of a brief paper in the Transactions of the Nova Scotia Institute of Natural History by the Rev. Dr. Honeyman, and an account of the geology of Dalhousie by Professor Hind, summarized by Sir William Dawson,[3] the first geological work done on the south side of the Restigouche River was the survey of northern New Brunswick in 1879-80 by R. W. Ells.[4] In 1886, the surface geology of this region was mapped by Chalmers.[5]

The results of the surveys of Ells and Chalmers, together with those of other geologists in adjacent areas, have been presented on a series of areal maps issued by the Geological Survey of Canada between the years 1882 and 1887.

During 1906 and 1908 Dr. J. M. Clarke, late director of the New York State Museum, published his valuable memoir on the early Devonian of eastern North America. The first part of volume II of this memoir contains an excellent account of the stratigraphy and paleontology of Dalhousie, to which the writer can add little except possibly a more detailed account of the volcanic history of the region.

Dalhousie and Vicinity

General Statement

With regard to the mode of formation of the igneous rocks near Dalhousie earlier observers seem to have held conflicting views. Ell's conception as to their origin is well exemplified by the following statement from Clarke's memoir.[6]

> "The village [Dalhousie] lies at the foot of a volcanic boss, Dalhousie Mountain, lying a mile or two back from the shore. From this, parallel apophyses extend seaward, and in between these have been caught the series of beds whose fauna here invites our attention."

In another place Clarke makes the following remarks:[7]

> "The water front of the village and the rocky islets skirting it belong to the northernmost and broadest of these volcanic arms. (Apophysis 1.)

[3] Acadian Geology, Edit. 4, 1891, p. 578. Also, J. M. Clarke, Early Devonic history of New York and eastern North America. Memoir 9, N. Y. State Mus., vol. II, 1908.
[4] Geol. Sur. of Canada, Report of Progress, 1879-80, Report D.
[5] Geol. Sur. of Canada, Report of Progress, 1887-88, Report N.
[6] Memoir 9, N. Y. State Mus., vol. II, 1909.
[7] XIIe Cong. Int. Geol., Guide Book, vol. I, p. 116, Ottawa, 1913.

. . . From Inch Arran . . . the diabase of this apophysis continues to Stewart's or Fossil Cove."

Then follows a description of apophyses 2 and 3.

Dawson held a different view as to the nature of these so-called apophyses, as he comments on the large amount of "bedded trap and volcanic ash" in the Dalhousie section and states that "their presence indicates the recurrence of volcanic eruptions at frequent intervals during the Upper Silurian period." In this connection Clarke points out that "sedimentation was contemporary with the volcanic eruptions, as evinced by the ash beds, and probably coeval with the outpouring over the sea-bottom of the greater volcanic masses."

In other words, although Clarke leans to the views of Dawson, he makes use of the term "apophysis," thus giving the impression that he considers these rocks as intrusives connected with the intrusion of Dalhousie Mountain.

SHORE SECTION—EEL RIVER TO DALHOUSIE

From the gap in the bar at the mouth of Eel River to a point about 1,200 yards southeast of Darlington postoffice, no outcrops were found except at low tide, when a number of patches of red Bonaventure conglomerate were laid bare. At the point referred to, a ridge about 60 feet in height rises abruptly from the level sandy beach. This ridge is underlain by a coarsely crystalline gabbro which is intrusive into the rocks of the Dalhousie Series and extends for about a mile inland.

Although on the Eel River road scattered outcrops of shales and tuffs overlie the gabbro, there are no outcrops along the beach until the Dalhousie beds, as described by Clarke, begin, about 600 yards north of the ridge. The series, which is composed of tuffs, lava flows, agglomerates, and sedimentary rocks, is as follows:

TABLE I

Dalhousie Beds and Associated Tuffs, Flows, et cetera

	Feet
Pyroxene andesite (fifth and fourth flows) (Stewart andesites)	40+
Intrusive andesite and breccia (Bon Ami andesites)	90
Pyroxene andesite (third, second, and first flows) (Stewart andesites)	85
Gap in section	320

Upper Dalhousie Beds

16. Arenaceous limestone with barren gray shale	25
15. Hard gray limestone	2
14. Thin-bedded shale with limestone	35
13. Ash bed	1
12. Blocky calcareous shale	2

FIGURE 1.—*Dalhousie Beds and Associated Igneous Rocks*

Upper Dalhousie Beds—Continued

	Feet
11. Ash bed with thin limestone and shale	30
10. Thin gray shale	10
9. Limestone and calcareous shale	75
8. Calcareous sandy shale	20
7. Coarse arenaceous limestone	7
Agglomerate and andesite (Barberie andesites) (with bed 6, silicified limestone)	220

Lower Dalhousie Beds

5. Hard gray limestone	10
4. Coarse yellowish white tuff	12
3. Hard gray arenaceous shale with limestone	40
2. Gray calcareous shale with limestone	125
1. Silicified limestone with shale	30
Basaltic tuff	30
Basalt	15
Palagonite tuff	200
Bed O, thin-bedded shale	30+
	1,454+

Bed O consists of thinly bedded shales, of which only the upper 30 feet are exposed. Immediately overlying these is a great thickness of dark greenish gray fragmental palagonite tuffs, forming a bank about one hundred and fifty feet high. These tuffs are very highly weathered and crumble easily in the hand. The backbone of the ridge of which these tuffs form the southern slope is composed of a thin flow of dark brown basalt. At the contact between the palagonite tuff and the basalt the shore turns sharply to the southeast, and this flow outcrops in vertical columnar masses along the shore for a distance of over 500 feet (see figure 1). Overlying this is a black basaltic tuff containing inclusions which closely resemble the underlying basalt. The tuffs extend around the small point about 150 feet east of their contact with the basalt; thence to the upper surface of the tuffs is about 30 feet, and at this point the fossiliferous Lower Dalhousie beds begin.

This series of tuffs, with the basalt flow, forms the so-called "apophysis 3," and it is believed that they emanated from the volcanic center which lies behind the town of Dalhousie. The basalt is simply a more basic representative of the great series of andesite flows from this source and is the earliest known flow of the Dalhousie Mountain series.[8]

[8] As many of the volcanic rocks of this area are of a very similar composition, use has been made of local names to indicate these different phases. The whole series of volcanic rocks has been given the name Restigouche Volcanic Series.

The contact of the basaltic tuffs with bed 1 is irregular, but as no oxidation of the tuffs was observed, the sediments are thought to have been deposited directly on them without any erosion interval. Bed 1 consists of a limestone which has been partially silicified, interbedded with calcareous shales, and is the only richly fossiliferous bed in the lower series.

In bed 2, which is a series of gray to yellowish calcareous shale with thin beds of limestone, only a few fossils were found. This is also true of the arenaceous beds which make up bed 3.

The highly altered yellowish gray, coarse-grained tuffs (bed 4), which overlie bed 3, are, apparently, unfossiliferous. They seem to have been formed by the subaqueous deposition of a coarse flaky ash, and their alteration has been so complete that they could not be referred to any of the igneous rock types in the area. Overlying this is an unfossiliferous hard gray limestone whose thickness is given as 10 feet, although the scattered outcrops along the water line, which appear to belong to this bed, would increase the thickness to over 80 feet.

The contact between this bed and overlying volcanic rocks is extremely irregular. For a distance of over 150 feet along the shore east of the point where the latter are first encountered, small patches of sedimentary rocks project through the sand. These fragments are apparently *in situ* and conform in dip and strike to beds 1-5 (dip 50 degrees north 10 degrees east). Finally, the so-called "inclusion" of limestone is reached.[9] This inclusion lies just above high-water mark and is composed of several beds of arenaceous limestone, with a total thickness of 10 feet. These beds contain corals and brachiopods as well as fragments of bryozoa and have been partially silicified. They dip to the north under the cliff of volcanic rocks overlying bed 5 and are protected from wave action by a mass of hard greenish gray andesite porphyry which underlies them.

The underlying rock is traversed by a number of small irregular veins of calcite and chlorite. None of these veins were seen to traverse either the sediments of the so-called inclusion (bed 6), or the overlying tuffs and flows.

It is believed that bed 6 is merely the remains of a sedimentary bed which lies disconformably upon this rock, and that if it were not for the erosive action of the sea these bodies would be seen continuing to the east. The marginal portions of the "inclusion" have not suffered any metamorphism, nor is the limestone altered in any way except for the small amount of silicification that has taken place. This silicification is

[9] Memoir 9, N. Y. State Mus., vol. ii, p. 11.

such as would develop in an arenaceous limestone under the influence of meteoric waters, and if it is claimed that it is due to contact metamorphism, then a similar explanation is necessary to explain the same phenomenon in bed 1, where silicification has taken place to almost as great an extent, although separated from any later igneous activity, except the deposition of tuff, by over 150 feet of sediments. The fact that the chlorite-calcite veins in the underlying rock do not traverse the sediments and were not observed in the overlying volcanic rocks indicates that they were formed before either of the later rocks were laid down. A petrographic study of the igneous rocks also shows a considerable difference in composition, and therefore this limestone body can not be termed an inclusion.

If the explanation that both bed 6 and the underlying igneous rocks formerly extended to the east is valid, then the irregular lower surface of the overlying tuffs can be easily explained. The area to the south was probably a land area and at some time after the deposition of bed 6 the sea retreated farther to the north, laying that bed bare. During the period of erosion which ensued a steep hill was formed, whose slope to the north was about 75 feet in 300, or 1 in 4. Then followed the deposition of over 200 feet of andesitic tuffs and flows, which buried this slope and preserved the configuration of the land beneath. Subsequent tilting of the series and the greater erosion of the softer sediments by wave action have isolated this limestone with a portion of the basement on which it rests.

Overlying beds 5 and 6 is a thick mass of volcanic rocks, which form a cliff 100 feet in height for a distance of over 1,000 feet along the shore. Their thickness is about 220 feet, of which the lower 100 feet is a green volcanic agglomerate containing bombs of irregular size and shape, some of which possess a diameter of over two feet. Small veins and patches of calcite occur abundantly throughout this agglomerate. Above it there is a greenish, finely crystalline, amygdaloidal flow which has been intruded prior to complete consolidation by a great number of irregular dikes of a highly amygdaloidal, glassy andesite. The earlier flow is traversed by a multitude of calcite veins, while in the later rocks, which are red in color, calcite is relatively uncommon. The ridge formed by these andesites crosses the road one-half mile to the west, but soon disappears beneath the valley south of Dalhousie Mountain. This disappearance of the ridge made up of these rocks and the fact that, although andesitic in character, they differ from the other andesites of the area leads to the conclusion that they came from a volcanic center which existed somewhere to the east.

Following the outburst of volcanic activity represented by these andesites, there was a return of marine conditions. That the subsidence was rapid is shown by the fact that the first bed (bed 7) above the lavas is a coarse-grained arenaceous limestone in which corals are abundant. There is no basal conglomerate nor detrital beds at the contact with the andesitic rocks beneath, and while the contact is irregular, this irregularity is probably due to the unevenness of the upper surface of the flow rather than to any erosion interval that may have taken place.

Although bed 13 is designated in Table I as an ash bed, while the others consist of limestone and shale, volcanic activity continued while all the beds from bed 7 to bed 14 were being deposited, and all of these beds contain a small percentage of tuffaceous material. Above bed 14 the section disappears, except for a few bands which project above the beach at low tide. These are referred to in Table I as beds 15 and 16.

Above bed 16 there is a gap in the section of about 320 feet, extending to the end of Stewart's Cove, where flows of pyroxene andesite (Stewart andesite) begin. Of these, there are three flows between the end of Stewart's Cove and Bon Ami Point, while to the north of the latter point there are two more flows of similar character.

Subsequent to the extrusion of these pyroxene andesites, local fracturing took place along the contact between the third and fourth flows. This was followed by the injection of an andesite sill, a breccia dike, and several other andesitic dikes. Further faulting followed these injections. The source of the dikes was apparently toward the east, as the breccia fingers out a couple of hundred yards west of Bon Ami Point, and the western terminations of several dikes may be found near by.

The ridge which has been formed by the andesites extends in a northeasterly direction to the road about half way between Dalhousie and Darlington; thence to a point about 2,000 yards west of the road, where it joins the south side of Dalhousie Mountain, the andesites being here cut by the mass occupying the plug of the ancient volcano.

Between Bon Ami Point and Inch Arran there is a gap of over 500 yards in the shore section. Inland, west of Dalhousie Mountain, there are no outcrops for a distance of 300 yards north of the ridge of pyroxene andesites, but the nature of the valley suggests the presence of sedimentary strata. Along the road south of the Campbellton Road, in the town of Dalhousie, there are outcrops of porphyritic hornblende andesite which forms a ridge about 700 yards long. These andesites are truncated by the andesites of Dalhousie Mountain.

Inch Arran Point is formed by a flow of red andesite which was the

forerunner of a series of flows and tuffs which have been given the name of Inch Arran andesites. These occur in gradually diminishing amount through a section of over 1,000 feet in thickness, which extends from Inch Arran to Point La Nim. East of Dalhousie there are no interbedded sediments, and there is evidence of at least one period when the surface was built up above sealevel and tuffs were deposited subaerially. Above the thick flow at the base of the series is a bed of tuffs about 125 feet in thickness. For the lower 75 feet the ash fills the interstices between water-worn pebbles and boulders, some of which are a foot in diameter. These pebbles and boulders must have been deposited just below sealevel, as the upper twenty feet of the overlying ash bed is much less sorted and stratified than the lower portion, as if the sealevel at this point had been only 30 feet above the boulders. Probably 99 per cent of the boulders are derived from igneous rocks, but there are a few fragments of sandstone and shale. No pebbles formed from plutonic rocks were found.

The town of Dalhousie and the mountain behind the town are underlain by a dense fine-grained pyroxene andesite, which represents the magma which solidified in the neck of the volcano during the cessation of volcanic activity. The islands in front of the town are believed to be a part of a sill which was injected from some part of the neck.

The shore section, which is the most nearly complete in the area, thus provides us with a series of tuffs and flows interbedded with sediments, and the following deductions may be made concerning the volcanic rocks:

1. The basaltic tuffs and flows below bed 1, including possibly the associated palagonite tuffs, and the Stewart andesites above bed 16 were deposited during periods of eruption of the volcano which occupied the site of the present Dalhousie Mountain.

2. The agglomerate and flows between beds 5 and 7, the intrusives in the pyroxene andesites above bed 16, and the Inch Arran andesites probably came from the east or northeast.

3. There is strong evidence of at least two, and possibly three, periods of emergence during the period of deposition of these rocks.

Region between Dalhousie and Campbellton

Although only two series of flows and tuffs were found east of Dalhousie Mountain which were believed to have been extravasated from this source, no fewer than five similar series were traced toward the west. Of these, the second is the most nearly continuous and extends for over twelve miles west of Dalhousie. To the south of McLeod's and Maple

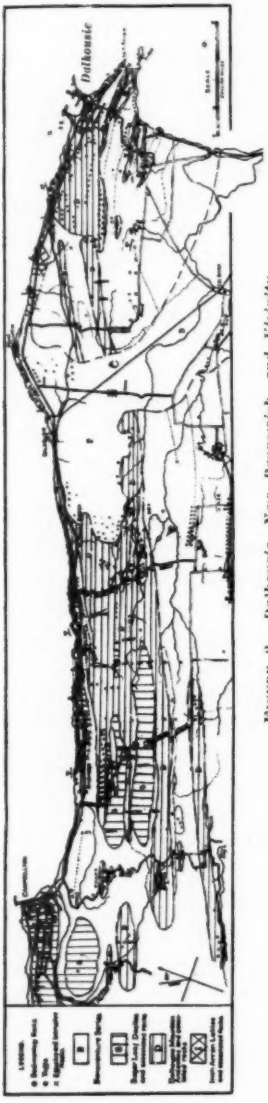

FIGURE 2.—*Dalhousie, New Brunswick, and Vicinity*

Green few sedimentary outcrops were found, the flows of the second, third, and fourth series being merged, in places, into one continuous series of andesites with some intervening flows of materials from other sources, and beds of tuffs. West of McLeod's new types of volcanic rocks commence to appear, the most abundant being series of dacitic flows which separate these three series of flows from Dalhousie Mountain. These have been correlated with the intrusive mass forming the Sugar Loaf behind Campbellton and have been given the name of Sugar Loaf dacites.

In addition to these dacites, still other rock types are found behind Campbellton; these appear to have come from sources still farther to the west.

A series of flows of pyroxene andesite occurs above the fourth series of Dalhousie Mountain andesites in the vicinity of Maple Green which differ from the latter rocks in texture. They resemble very closely certain rocks from what was taken to be a volcanic neck underlying the Bonaventure series about half a mile south of this place. This group (the Maple Green andesites) are therefore believed to represent a third volcanic neck and associated flows.

The Maple Green andesites do not continue more than half a mile west of their source, and the area lying between the fourth series of Dalhousie Mountain andesites and the coast is made up of interbedded tuffs and flows of either the Dalhousie Mountain or the Sugar Loaf type. The former do not extend past Richard's, while the latter rocks increase in abun-

dance to Campbellton and beyond. At Campbellton they are overlain along the shore by fish-bearing beds of later Devonian age.

The following table shows the succession of the principal rock types found in the area:

TABLE II

Order of Succession of the Restigouche volcanic Series and associated Rocks between Dalhousie and Campbellton, New Brunswick

Campbellton.	Richards.	McLeod's.	Maple Green.	West-Dalhousie-East.
Sugar Loaf. Intrusion.			Maple Green. Intrusion.	Dalhousie Mountain. Intrusion.
Third zone of dacites.	Under Baie des Chaleurs			
Interbedded andesites and dacites.			Maple Green andesites.	Under Baie des Chaleurs.
Fourth zone of Dalhousie Mountain andesites Second zone of Sugar Loaf dacites				Inch Arran latites and andesites.
Third zone of Dalhousie Mountain andesites First zone of Sugar Loaf dacites—tuffs, etc.				Hornblende-bearing andesites.
Second zone of Dalhousie Mountain andesites				Stewart andesites. Bon Ami dikes. Stewart andesites.
Tuffs and amygdaloidal andesites				Andesites: Beds 7-16. Barberie andesites. Beds 1-6.
First zone of Dalhousie Mountain andesites				Basalt, tuffs, etc. Bed O. Gabbro, tuffs, etc.
Sandstones, shales, limestones, with intrusive tonalite.				

PETROGRAPHY

GENERAL STATEMENT

Petrographically these rocks are relatively simple and possess few characteristics worthy of especial notice.

The more important rocks of the area are divided into the following groups:

Sugar Loaf dacites and associated rocks.
Inch Arran latites and andesites.
Dalhousie Mountain andesites (including Stewart andesites).
Maple Green andesites.
Bon Ami dacites and associated rocks.

SUGAR LOAF DACITES AND ASSOCIATED ROCKS

The Sugar Loaf dacites, which are abundant in the vicinity of Campbellton, are gray porphyritic rocks with phenocrysts of oligoclase or andesine, with some hornblende and quartz in a groundmass of feldspar and quartz. The presence of hypersthene is frequently suggested by aggregates of serpentine with outlines typical of those of hypersthene, and orthoclase occurs both in the form of phenocrysts and in the groundmass, but not in sufficient quantity to warrant the description of any of the rocks as latites. Black iron ore and apatite are constant accessories.[10]

The tuffs associated with the dacite flows are massive in structure and are composed of irregular fragments of quartz, orthoclase, oligoclase, andesine, and black iron ore in a very fine-grained, almost glassy base. Many of them are rhyolitic rather than dacitic in character. A vague tendency to stratification may be observed in the outcrop, and this is intensified in thin-sections of these tuffs.

INCH ARRAN LATITES AND ANDESITES

The lava-flows and associated tuffs which outcrop along the shore between Inch Arran and Dalhousie Junction are biotite-augite andesites and latites. When fresh, these rocks are greenish gray in color, with abundant red spots; they alter on weathering to a pinkish gray. The fresh varieties are composed of phenocrysts of orthoclase, microperthite, oligoclase, biotite, augite, and black iron ore in a groundmass composed

[10] A more complete account of the petrography of the Restigouche Volcanic Series may be found in the writer's unpublished thesis, McGill University, 1924. This thesis, together with the results of later field-work performed for the Geological Survey of Canada, will be published in a memoir of that Survey.

of small laths of feldspar and iron oxides with occasionally some interstitial glass.

The associated tuffs are reddish or greenish in color and in many places contain a profusion of bombs and rock fragments. They are largely vitreous tuffs and the rock fragments in the agglomerate are monzonitic in character.

DALHOUSIE MOUNTAIN ANDESITES

The pyroxene andesites, which are believed to be associated with the volcanic neck behind Dalhousie, vary in composition between augite andesite with a small amount of hypersthene and hypersthene andesite with little or no augite. They are usually dense rocks, dark brown to black in color, in which a few needle-like crystals of feldspar and frequently small grains of iddingsite may be distinguished in the hand specimen.

In thin-section they are found to consist of phenocrysts of augite, hypersthene, and andesine in a groundmass composed chiefly of andesine and black iron ore, although in some varieties augite, and more rarely hypersthene, is present in the groundmass. In a great many cases the hypersthene has been altered to iddingsite and in others to bastite.

The Stewart andesites which occur at Bon Ami Point are a variety of the Dalhousie Mountain andesite in which iddingsite derived from hypersthene is the sole phenocrystic mineral, while the groundmass is composed of an intergrowth of augite and andesine with black iron ore. Similar characteristics were noted in some rocks of the second zone of andesites west of Dalhousie Mountain, while the third zone is composed entirely of hypersthene andesites with little or no augite.

MAPLE GREEN ANDESITES

The Maple Green andesites from the volcanic neck are composed of coarsely granular rocks in which tabular grains of feldspar, hypersthene, with a maximum diameter of 8 and 2 millimeters, respectively, can be determined. In thin-sections phenocrysts of augite may also be observed. The groundmass is composed of glass.

In the flows, which are amygdaloidal, the phenocrysts are much smaller and the glassy groundmass has been partially devitrified.

BON AMI ANDESITE

This term is at present applied to the sheet injected between the third and fourth flows of Stewart andesite and the associated breccia and dikes.

The sheet is composed of an andesite in which phenocrysts of iddingsite, labradorite, andesine, and augite occur in a fine groundmass of andesine and rounded augite grains.

The accompanying dikes differ from this andesite in texture and in the presence of glass in the groundmass, while the breccia includes fragments of both types of rocks as well as small blocks of a magenta scoriaceous lava in a glassy groundmass.

A number of other types of massive andesites, amygdaloids, scoriæ, and tuffs also occur in the area which need not be described here.

SUMMARY OF MINERALOGICAL AND CHEMICAL CHARACTERS

The mineralogical composition of the different members of the Restigouche Volcanic Series may be outlined as follows:

TABLE III

	Sugar Loaf dacite.	*Inch Arran andesite.*	*Dalhousie Mountain andesite.*	*Maple Green andesite.*	*Bon Ami andesite.*
Quartz	A	C	—	—	—
Orthoclase	B	B	—	—	—
Microperthite	—	B	—	—	—
Oligoclase	A	A	—	—	—
Andesine	B	C	A	A	A
Labradorite	C	—	B	—	B
Biotite	—	A	—	—	—
Hornblende	A	—	—	—	—
Augite	—	A	A	A	A
Hypersthene	C	—	A	A	A
Iron ore	A	A	A	A	A
Apatite	B	A	A	—	—
Glass	B	B	B	B	A

A, invariably present; B, frequently present; C, occasionally present.

A study of the composition of the rocks comprising the Restigouche Series shows a great uniformity of mineralogical and chemical composition, as may be seen from the following table:

TABLE IV

Analysis of Rocks of the Restigouche Series
(Analyst, W. V. Howard)

	I	II	III	IV	V	VI
	Sugar Loaf dacite.	*Dalhousie Mountain andesite.*	*Bon Ami andesite.*	*Hypersthene andesite.*	*Inch Arran andesite.*	*Stewart andesite.*
SiO_2	62.99	56.74	54.87	50.72	48.33	47.15
Al_2O_3	18.03	18.41	19.64	21.25	19.48	28.62
Fe_2O_3	2.02	4.30	1.18	3.20	2.87	3.34
FeO	1.52	2.04	2.93	3.32	2.14	3.46
MgO	1.00	1.33	3.15	3.84	4.98	3.48
CaO	3.25	6.02	7.32	7.08	8.04	7.49
Na_2O	5.82	5.58	5.47	5.22	5.04	3.64
K_2O	1.05	1.13	1.47	2.56	2.72	0.70
H_2O	2.07	2.05	1.78	1.32	3.80	0.67
TiO_2	0.71	1.02	1.76	1.63	1.16	1.32
P_2O_5	0.29	tr.	tr.	pres.	——	pres.
MnO	0.09	0.12	0.16	tr.	0.05	0.12
CO_2	1.00	1.25	0.70	0.10	1.05	0.29
	99.84	99.99	100.43	100.29	99.66	100.28

Norms

Q	19.98	8.94	——	——	——	1.98
Or	6.67	6.12	8.90	15.57	16.12	3.89
Ab	49.25	47.16	46.11	29.34	24.63	30.92
An	7.78	21.76	24.46	26.97	22.52	35.86
Ne	——	——	——	7.95	9.66	——
C	4.39	——	——	——	——	8.67
Di	——	——	5.50	5.86	8.42	——
Hy	2.50	3.30	6.89	——	——	10.27
Ol	——	——	——	5.41	5.95	——
Mt	3.02	3.71	1.86	4.64	3.71	4.87
Il	1.37	1.98	3.34	3.04	2.13	2.43
Hm	——	1.76	——	——	0.32	——
Ap	0.68	——	——	0.34	——	——

		Class.	*Order.*	*Rang.*	*Subrang.*
I.	1″.4.2.(4)5	I Persalane	4 Britannare	2 Toscanase	5 Mariposose
II.	1(11).(4)5.3.(4)5	I Persalane	5 Canadare	3 Piedmontase	5 Kitlimose
III.	(1)11.5.3.(4)5	II Dosalane	5 Germanare	3 Andase	4 Andose
IV.	″11.5(6).3.4	II Dosalane	5 Germanare	3 Andase	4 Andose
V.	11.(5)6.″3.4	II Dosalane	6 Norgare	3 Salemase	4 Salemose
VI.	″11.5.2″.(4)5	II Dosalane	5 Germanare	2 Monzonase	5 Grenadose

RELATIONSHIPS WITH OTHER AREAS

In their dosodic to persodic character these rocks are similar in some degree to some pre-Cambrian rocks of New Brunswick and Maine.

There is, therefore, a recurrence of igneous activity after an extensive period of quiescence from magmas of very similar composition.

It might be expected that the rocks of the Restigouche Series would show a close connection with those of the contemporaneous Aroostook Series in Maine.[11] Hillebrand's analyses of the rocks found by Gregory show that they form two distinct classes, of which the more basic bears a fairly close correspondence to the Restigouche Series. This relationship is shown in Table V:

TABLE V

Comparison of Analyses of the Basic Rocks of Aroostook, Maine, and Those of the Restigouche Series, near Dalhousie, New Brunswick.

	Aroostook.		*Restigouche.*	
	Extremes	*Average.*	*Extremes.*	*Average.*
	Per cent.		*Per cent.*	
SiO_2	42–61	50.0	47–63	53.5
Al_2O_3	15–17	16.0	18–29	20.8
Fe_2O_3	2–8	4.3	1–4	2.8
FeO	3–10	6.8	2–3	2.5
MgO	3–7	4.5	1–5	3.0
CaO	3–7	5.8	3–8	6.3
Na_2O	4–5	4.2	4–6	5.2
K_2O	1–2	1.3	1–3	1.7
TiO_2	1–3	2.0	1–2	1.0

NOTE.—The Aroostook rocks include: Andesite, Edmund's Hill; Diabase, Aroostook Falls; Diabase, Mars Hill; Teschenite, Mapleton Village.

The similarity is, therefore, not so great as the contemporaneity and proximity of these two volcanic areas would suggest. If the acid rocks from the Aroostook area are included in the comparison, the disparity is even greater. It may be, however, that the rocks are consanguineous, but that the Maine rocks occur on the outer border of the comagmatic region, and would therefore show more divergent characteristics than those portions of the magma nearer the interior.

A very close resemblance exists between the Restigouche rocks and such rocks as the carmeloite from Carmelo Bay, California; the diabases from Point Bonita, and the andesites from the John Day Basin. These rocks are not only similar in mineralogical composition to the andesites of New Brunswick, but chemically they are also similar. This relationship is shown in Table VI:

[11] H. E. Gregory; Contributions to the geology of Maine, Bull. 165, U. S. Geol. Surv.

TABLE VI

	I	II	III	IV	V	VI
SiO_2	57.53	52.83	49.45	45.59	57.49	56.74
Al_2O_3	16.47	17.67	17.58	20.90	17.22	18.41
Fe_2O_3	4.42	7.50	3.41	2.49	4.34	4.30
FeO	3.23	1.68	3.41	4.36	3.01	2.04
MgO	1.32	2.47	4.05	8.95	3.38	1.33
CaO	6.16	7.35	7.20	7.57	6.48	6.02
Na_2O	4.13	6.61	5.83	4.89	3.90	5.58
K_2O	2.09	2.52	1.57		1.30	1.13
H_2O	1.02	Ign. 2.32	4.34	5.06	H_2O 1.99	2.05
TiO_2	0.91	tr.	2.23	——	1.22	1.02
MnO	0.17	——	tr.	——	0.22	0.12
P_2O_5	0.63	——	——	——	0.28	pres.
CO_2	2.47	——	——	——	——	1.25
	100.55	100.95	99.07	99.90	100.73	99.99

I. Andesite, Blackford Hill, Pentland Hills. Analyst, W. Pollard.
II. Carmeloite, Carmelo Bay.
III. Spheroidal basalt, Point Bonita.
IV. Diabase, Point Bonita.
V. Hypersthene andesite, Hald's Cañon, John Day Basin. F. C. Calkins.
VI. Andesite, Dalhousie Mountain, Dalhousie, New Brunswick. W. V. Howard.

The rocks from the Pacific coast are Tertiary in age, and in order to find any contemporaneous rocks which are similar to the Restigouche volcanics it is necessary to cross the Atlantic.

In the British Isles there was widespread volcanic activity during the Devonian period, especially in Lower Old Red Sandstone time. The formation of the great fresh-water lakes of Great Britain north of the Bristol Channel coincides with the beginning of the Devonian, and this marks the opening of a prolonged period of volcanism in the newly formed land area. Sir Archibald Geikie gives an excellent summary of the great development of vulcanicity in this period in his treatise on the ancient volcanoes of Great Britain.

Diabase lavas are typically developed in the Pentland Hills, while andesites constitute by far the largest proportion of the lavas. In these, plagioclase feldspars form the usual porphyritic constituents, but mica or one or more pyroxenes may also occur as phenocrysts. The andesites in the vicinity of Loch Melfort have been described[12] as "usually purple and sometimes grayish andesites, sometimes compact and sometimes highly vesicular. . . . Porphyritic crystals of feldspar are only rarely seen, though small specks of a reddish brown mineral (iddingsite?) are often very common."

The comparatively small number of dikes associated with the Restigouche volcanoes is remarkable, and it is surprising to note the same

[12] Geology of the seaboard of Mid Argyll. Mem. Geol. Surv. Scot., 1909, p. 65.

feature in the contemporaneous Scottish volcanic series. According to Geikie,[13] "one would expect to meet with a network of dikes in and around the volcanic vents; but even there they are usually not conspicuous either for number or size. In the great vent of the Braid Hills only a few have been noticed."

The analysis of an andesite from the Pentland Hills (see Table VI, column I), shows that some of the Scottish rocks are chemically identical with those of the area around Restigouche. Thus we see on both sides of the Atlantic contemporaneous outbursts of volcanic activity, and that the lavas which were extruded were very similar, both mineralogically and chemically.

Summary

In his general conclusions, Clarke[14] points out that the Saint Alban's beds of Gaspé and the Dalhousie beds were deposited in two passages which seem to have converged toward the west and south. The Dalhousie passage became filled at the close of Helderberg time, while the northern passage remained open at least until the Onondaga period.

In the preceding pages of this paper the writer has endeavored to give some idea of the nature of the deposition in the Dalhousie passage, where sedimentation and deposition of volcanic material succeeded several times in raising the level of the land above sealevel during Helderberg time, and it is probable that the earlier date of final emergence of the Dalhousie passage is due to the accumulation of flows and tuffs.

The igneous rocks which make up this volcanic series differ from the rocks of neighboring petrographical provinces, although it is possible that the rocks of the Aroostook area of Maine are consanguineous with them. There is, however, a striking resemblance, both mineralogically and chemically, between these rocks of the Restigouche Series and some of the Tertiary eruptions on the western border of the continent on the one hand and the contemporaneous volcanic rocks of the Old Red Sandstone in the British Isles on the other.

[13] Ancient volcanoes of Great Britain, p. 293.
[14] Op. cit., vol. ii, pp. 153-162.

Appendix: Range and Distribution of the Dalhousie Fauna

The following table is copied from Clarke's memoir,[15] with the addition of any other occurrences noted by the writer:

	1	2	3	6	7	8	9	10	11	12	13	14	16	He	SA	Ch	Co
Spirorbis sp.	—	—	—	—	—	—	x	—	—	—	x	—	—	—	—	—	—
Pterygotus sp.	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
Phacops logani, Hall v. *gaspensis* Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	(x)	—	—	—
Dalmanites micrurus Green	—	—	—	—	—	—	—	—	x	—	—	—	—	x	—	—	—
Bronteus barrandii Hall v. *major* Clarke	—	—	—	—	—	—	—	x	—	—	—	—	—	(x)	x	—	—
Proetus sp.	—	—	—	—	—	x	x	—	—	—	—	—	—	—	—	—	—
Beyrichia kloedeni McCoy cf. v. *acadica* Jones	—	—	—	—	—	—	—	—	—	x	—	—	—	(x)	—	—	—
Pachydomella nov.	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—
Kloedenia marginalis Ulrich and Bassler	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
K. manliusensis (Weller)	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
K. retifera Ulrich and Bassler	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
K. sussexensis (Weller)	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
K. punctillosa Ulrich and Bassler	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
Kloedenella pennsylvanica (Jones)	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—
K. halli (Jones)	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—
Orthoceras cf. *longicameratum* Hall	—	—	—	—	—	—	—	—	x	—	—	—	—	x	—	—	—
Kionoceras cf. *rhysum* Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	—	x	—	—
Holopea enjalrani Clarke	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
H. enjalrani v. *corrugata* Clarke	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
H. cf. *antiqua* Vanuxem v. *pervetusta* Conrad.	—	—	—	—	—	—	—	—	—	—	x	—	—	x	—	—	—
Coelidium streboceras Clarke	—	—	—	—	—	—	—	—	x	o	o	o	—	—	—	—	—
C. tenue Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	x	—
Melissosoa compacta (Hall)	o	—	—	—	—	—	—	—	x	—	—	o	—	x	—	—	—
Platyceras sp.	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—
Euomphalus disjunctus Hall	—	—	—	—	—	—	—	—	x	—	—	—	—	x	—	—	—
Pterinopecten denysi Clarke	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	(x)
P. cf. *proteus* Clarke and *wulfi* Frech?	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	(x)

Numbers refer to the beds of the Dalhousie Series.
He, Helderberg of New York; SA, Saint Albans beds of Gaspé; Ch, Chapman sandstone; Co, Coblentzian of Europe.

[15] Vol. II, pp. 13-15.

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[15] Vol. II, pp. 13-15.

Range and Distribution of the Dalhousie Fauna.—Continued.

	1	2	3	6	7	8	9	10	11	12	13	14	16	He	SA	Ch	Co
Pterinea intercostata Clarke	o	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	(x)
P. cf. *pseudolævis* Oehlert	—	—	—	—	—	—	x	—	—	—	x	—	—	—	—	—	(x)
P. fasciculata Goldfuss v. *occidentalis* Clarke	o	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	(x)
P. (*Pteritonella?*) *incurvata* Clarke	—	—	—	—	—	—	o	—	x	—	—	—	—	—	—	(x)	—
P. brisa v. *vexillum* Clarke	—	—	—	—	—	x	—	x	—	—	—	—	—	—	—	(x)	—
Pteritonella passer	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	(x)	—
P. hirundo Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
Mytilarca dalhousie Clarke	—	—	—	—	—	—	x	x	x	—	—	—	—	(x)	—	—	—
Modiomorpha impar Clarke	—	—	—	—	—	—	x	x	x	—	—	—	—	—	—	—	—
Goniophora curvata Clarke	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—
G. tethys (Billings)	—	—	—	—	—	—	—	o	—	—	—	—	—	—	x	—	—
Sphenotus ellsi Clarke	—	—	—	—	—	—	x	—	x	x	x	o	o	—	—	—	—
Carydium gregarium Beushausen	—	—	—	—	—	—	x	x	x	—	—	—	—	—	—	—	x
C. elongatum Clarke	o	—	—	—	—	—	x	x	x	—	—	—	—	—	—	—	(x)
Cypricardella norumbegæ Clarke	—	—	—	—	—	—	x	—	x	—	x	o	—	—	—	—	—
Macrodus matthewi Clarke	—	—	—	—	—	—	—	x	x	—	—	—	—	—	—	—	—
M. ? baileyi Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
Janeia sp. ?	—	—	—	—	—	—	x	—	x	—	—	—	—	—	—	—	(x)
(*Pectunculus ?*) *plutonicus* nov.	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—
Palæoneilo (*Nuculites*) *folles* Clarke	—	—	—	—	—	—	—	—	x	x	x	o	—	—	—	—	—
Nuculana (*Ditichia*) *securis* Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	(x)
Conocardium incarceratum Clarke	—	—	—	—	—	—	—	—	x	—	—	—	—	(x)	—	—	(x)
Rensselæria stewarti Clarke	—	—	—	—	—	—	o	o	x	—	o	o	—	—	—	(x)	(x)
Sieberella pseudogaleata Hall	x	—	—	—	—	—	—	o	o	—	—	—	—	x	—	—	—
Camarotæchia	—	—	—	—	—	—	—	x	—	—	—	—	—	(x)	—	—	—
Uncinulus nobilis Hall	—	—	—	—	—	—	—	o	—	—	—	—	—	—	—	—	—
Spirifer concinnus Hall	x	x	o	o	o	x	x	x	o	o	o	o	o	x	x	—	(x)
S. coralliensis (Ulrich?)	—	—	—	—	—	o	—	—	—	—	—	—	—	x	—	—	—
S. perlamellosus Hall	—	—	—	—	—	x	x	—	—	—	—	—	—	(x)	—	—	—
Cyrtina chalazia Clarke	—	—	—	—	—	—	x	—	—	—	—	—	—	(x)	—	—	—
Meristella princeps Hall	x	—	—	—	—	—	—	—	x	—	—	—	—	x	—	—	—
M. lævis Hall	o	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—
Nucleospira concentrica Hall	—	—	—	—	—	—	x	—	—	—	—	—	—	x	—	—	—
Trematospira perforata Hall v. *atlantica* Clarke	—	—	—	—	—	—	x	—	—	—	—	—	—	(x)	—	—	—

Range and Distribution of the Dalhousie Fauna.—Continued.

	1	2	3	6	7	8	9	10	11	12	13	14	16	He	SA	Ch	Co
Rhyncospira globosa Hall	o	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—
Atrypa reticularis Linné	—	o	—	—	o	o	x	x	x	—	—	—	—	x	x	—	—
Stropheodonta varistriata Conrad	—	—	—	—	—	x	x	o	—	—	—	—	—	x	x	—	—
S. patersoni Hall prot. *bonamica* Clarke	o	—	—	—	—	x	x	—	—	—	—	—	—	—	(x)	—	(x)
S. (*Brachyprion*) *major* Clarke	x	—	—	—	—	x	x	—	o	—	—	—	—	—	—	—	—
S. (*B.*) *schuchertana* Clarke	x	—	—	—	—	x	x	—	—	—	—	—	—	—	—	—	—
Leptostrophia becki Hall	o	—	—	—	o	x	x	—	x	—	—	—	—	x	—	—	—
Strophonella punctulifera Conrad	x	o	—	—	o	x	x	o	—	—	—	—	—	x	x	—	—
Leptæna rhomboidalis Wilckens	x	o	o	o	o	x	x	o	o	—	—	—	—	x	x	—	—
Leptænisca concava Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—
Orthothetes (*Schuchertella*) *radiatus* Hall	—	—	—	—	—	—	—	—	x	—	—	—	—	x	—	—	—
Schizophoria multistriata Hall	x	—	—	—	o	o	x	o	o	—	—	—	—	x	—	—	—
Rhipidomella hybridoides Clarke	o	x	o	—	—	o	o	o	—	—	—	—	—	—	—	—	—
R. numus Clarke	o	—	—	—	—	—	x	o	—	—	—	—	—	—	—	—	—
Craniella agaricina Hall and Clarke	—	—	—	—	—	—	x	—	—	—	—	—	—	x	—	—	—
Crania	—	—	—	—	—	—	—	x	—	—	—	—	—	(x)	—	—	—
Pholidops ovatus Hall	—	—	—	—	—	x	x	x	—	—	—	—	—	x	—	—	—
Orbiculoidea sp	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
Fenestella crebipora Hall	o	—	—	o	—	o	o	—	—	o	o	—	—	x	—	—	—
Alveolites squamosus Billings	—	—	—	—	—	—	o	—	—	—	—	—	—	—	—	—	—
Favosites hemisphericus M-E and H.	x	—	—	o	o	—	o	x	o	—	—	o	x	—	—	—	—
F. helderbergiæ Hall	x	—	—	o	o	—	o	x	o	—	—	o	x	x	—	—	—
Aulopora tubæformis Goldfuss	—	—	—	—	—	o	—	—	—	—	—	—	—	—	—	—	—
Synaptophyllum simcoense Billings	—	—	—	—	—	—	—	—	o	—	—	—	—	—	—	—	—
Halysites catenularis Lamarck	—	—	—	—	—	—	—	x	—	—	—	—	x	—	—	—	—
Zaphrentis (*Amplexus*) *shumardi* M-E and H.	x	—	—	o	o	o	o	x	o	o	o	o	x	—	x	—	—
Heliophyllum sp.?	—	—	—	—	o	—	—	—	—	—	—	—	—	—	—	—	—
Cyathophyllum radiculum Rominger?	—	—	—	—	—	o	—	—	—	—	—	—	—	x	—	—	—
Streptelasma calciculum Hall	o	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stromatopora antiqua Nicholson and Murie	o	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dictyonema splendens Billings	—	—	—	—	—	—	—	x	—	—	—	—	—	—	x	—	—
Hindia fibrosa Roemer (sp.)	—	—	—	—	—	x	x	—	—	—	—	—	—	x	x	—	—

NOTE.—New occurrences indicated by "o."

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TACONIC FOLDING IN PENNSYLVANIA[1]

BY B. L. MILLER

(Presented in abstract before the Society December 30, 1925)

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BRIEF REVIEW OF THE PRESENT STATUS OF THE TACONIC PROBLEM

In geology, and probably in all lines of research, there is a tendency to perpetuate established views long after evidence leading to contrary conclusions has been obtained. Likewise we have other examples of certain opinions being abandoned too quickly because of some supposedly good evidence that would seem to demand other explanations. Our textbooks, which in every case must be mainly compilations, are largely responsible for this situation. The ordinary investigator finds it easy to consult such sources and a task, frequently beyond his available time, to read and digest the mass of other literature bearing on his problem. It is, therefore, well from time to time to have general reviews of accumulated literature, with attempts to properly evaluate conflicting data. Such a

[1] Manuscript received by the Secretary of the Society September 26, 1925.

NOTE.—New occurrences indicated by "q."

review of the evidence in support of the belief in the Taconic Revolution was undertaken a few years ago by Mr. Thomas H. Clark.[2] It was particularly timely, as the belief in extensive earth movements resulting in the formation of mountains and in extreme metamorphism of earlier sediments at the close of the Ordovician had long been held and was described in our textbooks, despite the fact that various writers had brought forth evidence from different places that seemed to be contradictory. From his own observations and the work of others, he has made a strong case against a late or post-Ordovician period of mountain-folding in the eastern part of the United States and Canada. He concludes "that the only orogenic movements at the close of the Ordovician of which we have any record were localized in eastern and southeastern New York State, and that beyond this region there is no evidence of the Taconic Revolution."

Schuchert[3] reaches the same conclusion. In discussing this period he says:

"All of the confirmed evidence of mountain-making is restricted to a narrow and not long area in the State of New York. For the present, then, the Taconic disturbance must rest upon what is known, but the chances are good that a wider field of orogeny will be proved along the western side of the New Brunswick geanticline."

Schuchert attributes the regional metamorphism by which the quartzites, slates, and marbles of Vermont and adjoining States were formed to the movements of the Appalachian Revolution.

Keith, in an elaborate discussion[4] of Appalachian structure, dismisses the subject of Taconic folding in the following statements:

"Between the Ordovician and Silurian a slight movement of this nature [folding] took place in a small part of southeastern New York and in southern Maine. This has been called the Taconic Revolution; but it is too unimportant for such a designation, and it is not exhibited in the Taconic Range."

On a later page, in a general summary of Appalachian movements, he states that "westward tilting of the Appalachian region," accompanied with "slight local folding in southeastern New York, New Jersey, Maine, and New Brunswick," took place in the late Ordovician.

Other geologists have likewise changed their minds in regard to the importance of the Taconic Revolution, and to the writer it appears that

[2] Thomas H. Clark: A review of the evidence for the Taconic Revolution. Proc. Boston Soc. Nat. Hist., vol. 36, no. 3, 1921, pp. 135-163.

[3] C. Schuchert: Textbook of Geology. Part ii, Historical Geology, second revised edition, 1924, p. 244.

[4] A. Keith: Outlines of Appalachian structure. Bull. Geol. Soc. Am., vol. 34, 1923, pp. 309-380.

there is at present a trend to the other extreme, and that the tendency to minimize the effects of the post-Ordovician disturbances is being carried too far. Admittedly it has been shown that the evidence used by Dana in support of the Taconic Revolution is less conclusive than was generally assumed, and that we must abandon the term unless more positive evidence is forthcoming.

The writer is not familiar with the stratigraphic and structural problems of New England and southeastern Canada, as the result of field investigations, but he is not convinced that the evidence obtained in those regions, as indicated in the literature, forbids Taconic folding followed by erosion, and hopes that the geologists working in those sections may succeed in obtaining positive proof of the existence or absence of mountain-building forces at the close of the Ordovician. He does wish, however, to bring to the attention of those interested in the problem some facts that seem to have been overlooked. Clark, in his review of the situation, does not mention any Pennsylvania localities. Several of these seem to the writer to furnish important evidence.

Throughout the Appalachian region the contact between the Hudson River or Martinsburg shales and the overlying sandstones is seldom exposed. Although streams cross the contacts in several places, hillside debris from the sandstones or glacial or alluvial deposits largely conceal the contacts. Artificial excavations for railroads or quarries supply almost the only entirely satisfactory evidence. It is, therefore, not surprising that we have so few good sections exposed to examination, nor that northern New Jersey contributes almost nothing to our solution of the problem.

Throughout Pennsylvania generally the contact between the Martinsburg and Medina (Shawangunk) strata forms a marked topographic feature, due to the relative ease with which the Martinsburg strata, mainly shales, have been eroded in comparison with the very resistant overlying Medina quartzitic sandstones and conglomerates. The contact is near the base of the ridge and is almost everywhere completely obscured by heavy talus heaps. For that reason we must obtain our evidence as to the relations between the two series of strata entirely from a few rather widely separated localities.

Evidences of Taconic Folding in New York

General statement

For the sake of comparison, it may be well to briefly summarize the situation in southeastern New York localities where admittedly there

was folding and subsequent erosion of the Hudson River strata before the deposition of the Shawangunk. The two localities that furnish conclusive evidence of this disturbance are Rondout and Otisville. Becrafts Mountain, located about a mile southeast of Hudson, Columbia County, New York, has also been cited by Dana and others as furnishing evidence of Taconic folding because of a probable unconformity, but the evidence there is not quite conclusive. Davis,[5] in describing the region, says:

"The relative position of the Hudson River strata and the overlying limestones is the point of most importance and interest, and the weight of evidence seems to be in favor of nonconformity, though this relation is not nearly so well shown here as in the remarkable exposure in the old cement quarries at Rondout, on the other side of the Hudson, about 30 miles farther south."

RONDOUT, NEW YORK

The unconformity at Rondout, New York, has been described by many writers. Davis[6] and Van Ingen and Clark[7] have described the locality in considerable detail. The Hudson River (Normanskill) shales, dipping 60 degrees northeast, are unconformably overlain by the Wilbur limestone of the Cayugan series of Silurian age, dipping 30 degrees northwest. The contact is a very irregular one and can not possibly be explained by faulting, as shown in the illustration given by Van Ingen and Clark. The only interpretation suggested is that there was pronounced tilting or folding of the strata after the deposition of the Hudson River beds and subsequent erosion.[8]

"The nonconformity represents a period of land conditions in this vicinity which continued through the epochs of deposition of the Shawangunk grit, the Medina sandstone, the Clinton limestone and shale, and the Rochester shale and possibly the Lockport limestone" (page 1210).

OTISVILLE, NEW YORK

Just west of Otisville, New York, in a cut of the Erie Railroad, there is an unconformable contact between Hudson River (Martinsburg) shales and overlying Shawangunk conglomerates. The exposure has been described and figured by several writers.[9] Both series dip to the

[5] W. M. Davis: Becrafts Mountain. Amer. Jour. Sci., 3d ser., vol. 26, 1883, pp. 381-389.

[6] W. M. Davis: The nonconformity at Rondout, N. Y. Amer. Jour. Sci., 3d ser., vol. 26, 1883, pp. 389-395.

[7] Van Ingen and Clark: Disturbed fossiliferous rocks in the vicinity of Rondout, N. Y. New York State Museum Bulletin No. 69, 1903, pp. 1176-1227.

[8] J. M. Clarke: The Eurypterus shales of the Shawangunk Mountains, in eastern New York. New York State Museum Bulletin No. 107, 1907, pp. 293-326.

[9] C. Schuchert: Silurian formations of southeastern New York, New Jersey, and Pennsylvania. Bull. Geol. Soc. Am., vol. 27, 1916, pp. 531-554. Textbook of Geology, Historical Geology, second revised edition, 1924, p. 263.

northeast, but the difference in amount of dip is about 15 degrees. Schuchert states that "the basal 7 feet of the Shawangunk is a conglomerate, with the quartz pebbles ranging between .75 and 1.25 inches; there is also an occasional one of the Hudson River sandstone." Plainly, there was a tilting of the strata and a period of erosion here between the deposition of the shales and the basal conglomerates.

The evidence from the cited southeastern New York localities does not seem to have been disputed, although Clark[10] raises the question as to whether they are "chance occurrences" or "indications of conditions that existed over a vastly wider area."

Evidences of Taconic Folding in New Jersey

Although the Shawangunk and Hudson River formations are both developed in New Jersey as continuations southwestward from the Otisville, New York, locality, Kümmel, Weller, and others state that nowhere in the State has the contact between the two been observed.

> "In the Green Pond Mountain region a conglomerate very similar to that of the Kittatinny Mountain forms the crests of Green Pond, Copperas, and Kanouse mountains and rests unconformably upon the subjacent formation, which is sometimes the Kittatinny limestone and sometimes the pre-Cambrian crystalline rocks." [11]

If, therefore, the Green Pond conglomerate and the Shawangunk represent the same series, as all those who are familiar with the situation believe, we seem to have evidence of either an extensive overlap or of a period of disturbance and erosion between the deposition of the Hudson River and Shawangunk beds.

Evidences of Taconic Folding in Pennsylvania

General statement

Although southeastern New York has recently been cited as the region furnishing best evidence of Taconic folding, the following descriptions of Pennsylvania localities are believed to furnish as good or even better evidence:

Delaware Water Gap

At the Delaware Water Gap the Delaware River cuts across the contact of the Shawangunk (Medina) sandstones and conglomerates and the

[10] Op. cit., p. 156.

[11] S. Weller: The Paleozoic faunas. Geol. Survey of N. J., Report on Paleontology, vol. iii, 1903, p. 54.

underlying Martinsburg shales and slates. The writer has failed to find any exposure showing the contact, although Schuchert[12] reports a disconformable contact "at the southeastern end of the Gap, on the Pennsylvania side," and records a "great break," with all of the Richmondian absent. Slate pebbles are present in the conglomerate, which Schuchert explains as intraformational shale pebbles. Chance[13] questions "whether these are slate pebbles or portions of the slaty partings which are found between the beds." White[14] states definitely that "the lower portion (of the 'Oneida') contains many chips and fragments of the number III (Martinsburg) black slate, thus showing that the latter formation was subjected to erosion at the time the Oneida was deposited."

The writer has examined the exposures several times and is convinced that most of the slate pebbles in the basal Medina conglomerates have been derived from the underlying Martinsburg black slates. Some, however, are intraformational. The section, therefore, seems to indicate some movements and subsequent erosion after the deposition of the Martinsburg and before the laying down of the Medina, even though no definite unconformity can be established.

LEHIGH GAP

Where the Lehigh River cuts through Blue Mountain we have one of the best exposures of the unconformable contact of the Medina ("Oneida") conglomerate and the underlying Martinsburg. White[15] described this unconformability, but in the same volume, in a prefatory letter and in footnotes, Lesley[16] explains the "apparent nonconformability" as due to a local fault. Prime[17] makes the following positive statement:

> **"At the junction of the slates with the Oneida conglomerate [number IV] they are finely exposed and are seen dipping *conformably* beneath the mountain rocks."**

He also argues at length for the conformability of the two formations throughout Pennsylvania. Schuchert[18] describes the contact as "disconformable" with a "great break" and the absence of all the Richmondian.

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[12] C. Schuchert: Silurian formations of southeastern New York, New Jersey, and Pennsylvania. Bull. Geol. Soc. Am., vol. 27, 1916, p. 546.

[13] H. M. Chance: Special survey of the Delaware Water Gap. Pa. Sec. Geol. Survey, Rept. G6, 1882, p. 347.

[14] I. C. White: Geology of Pike and Monroe counties. Pa. Sec. Geol. Survey, Rept. G6, 1882, p. 237.

[15] Op. cit., pp. 81, 150-151.

[16] Pp. xxi, 80, 150.

[17] F. Prime, Jr.: Pa. Sec. Geol. Survey, Rept. D3, vol. i, 1883, pp. 32-35, 152.

[18] Op. cit., p. 548.

It is thus shown that there has existed considerable difference of opinion as to whether the section in the Lehigh Gap revealed any unconformity or not. The disagreement was largely due to unsatisfactory exposures. In fact, it was not until the excavations for the tracks of the Lehigh and New England Railroad in 1912 that positive evidence of an unconformity was obtained. The progress of the cutting was followed by the writer and his colleagues, and although the section is at present less satisfactory than at that time, the conclusions then reached can be easily confirmed by the present exposures.

The underlying Martinsburg slates dip 13 degrees steeper than the typical basal conglomerates that rest on the truncated edges of the slate. There is also a variation of 25 degrees in the strike of the two series. The contact is a sharp one and is unquestionably an unconformity and not a fault, as suggested by Lesley. Moreover, the lowest beds of the Medina are typically basal conglomerates.

Perhaps the best evidence of Taconic folding and metamorphism that the section reveals is the presence of sericitized slate pebbles in which there is no orientation of the cleavage planes with reference to the bedding of the conglomerates, nor do the cleavage planes of the separate pebbles show any parallelism. The slate pebbles have evidently been derived from the Martinsburg and likewise most of the quartz pebbles probably owe their origin to the same formation, as quartz veins are abundant in the Martinsburg. Pebbles of chert, which are common, must have come from the underlying Cambrian and Ordovician limestones. To the writer the un-oriented sericitized slate pebbles seem to furnish valuable evidence of strong post-Martinsburg and pre-Medina folding and metamorphism and the unconformable contact gives proof of a period of erosion.

SCHUYLKILL GAP

Blue Mountain is cut by the Schuylkill River at Port Clinton, Pennsylvania, in a similar manner as by the Lehigh and Delaware. The Port Clinton section is one of the best for study in the State because of three excellent exposures of the contact of the Martinsburg and Medina in the railroad cuts of the Pennsylvania and Reading railroads. This section has received little attention because of a probable misinterpretation of structure by Chance,[19] when he studied and prepared a section of the Gap in 1874. He shows the contact as an "upthrow fault of at least 3,000 feet." This idea has generally prevailed and is mentioned in the litera-

[19] H. M. Chance: Section at the Schuylkill Gap. Report G6, Pa. Sec. Geol. Survey, plate v, 1882.

ture by a number of writers. Lesley[20] gives the following description of the fault at this place:

"At this interesting locality the bottom of number IV is wholly separated from the slates of number III by a vertical fault, on the north side of which the sandstones of IV rise vertically into the air, making the crest and north slope of the mountain. On the south side of the fault the slate formation number III is sheared off like a cake of cheese, the edges of the slates abutting nearly horizontally square against the upturned bottom plate of Oneida conglomerate. It is impossible to affirm that it is actually the bottom layer of the Oneida, but there is very little reason to doubt it. Seeing that when the break took place and the whole mass of number IV was turned up at right angles, it is probable that it was turned up as a solid mass, and that the lower surface of the bottom bed acted as a grinding surface against the edges of the slates."

The only correct published explanation of the contact known to the writer is given by Grabau[21] in his recently published Textbook on Historical Geology. He gives an illustration of the contact and calls it an unconformity.

The writer has recently reexamined the sections and finds that there is satisfactory proof of the contact being an unconformity. The best exposure is in the cut of the Pennsylvania Railroad on the west side of the Schuylkill River. The Medina sandstone dips 81 degrees north and the Martinsburg shales and sandstones dip 14 degrees south. The strike of the two series is approximately the same, north 78 degrees east. No slickensiding is present at the contact and the underside of the Medina layer in contact with the truncated edges of the Martinsburg strata is rough and irregular. Had there been extensive faulting, slickensides would surely have been preserved, as they are well shown in both series of rocks a short distance on either side of the contact. Several minor faults in the Martinsburg have the slickensides preserved, both in the interbedded gray and brown calcareous sandstones and in the black shales. Furthermore, there is no bending of the strata near the contact, as would surely have occurred if there had been a fault of sufficient magnitude to bring the two series of beds into contact at approximately right angles.

The Schuylkill Gap section, as drawn by Chance from this exposure, is satisfactory as a generalized section except for his misinterpretation of the contact. The scale that he adopted scarcely permits the showing of the minor faults mentioned.

About one-fourth mile east of the former locality the contact has been

[20] J. P. Lesley: Summary. Final Report, Pa. Sec. Geol. Survey, vol. I, 1892, p. 674.
[21] A. W. Grabau: A textbook of geology. Part II. Historical Geology, 1921, p. 293.

exposed by excavation work during 1925 by the Reading Railroad. Here the exposures are similar, except that there has been some movement along part of the contact. The fault, however, leaves the contact and is continued in the Medina basal conglomerates. The displacement seems to be very slight.

At the third exposure, also along the Reading Railroad and about one-fourth mile farther east, the Martinsburg strata are again in contact with the Medina, the former practically horizontal and the latter vertical. The strata are exposed on both sides of the railroad, although on the east side the shales are so decomposed at the contact as to be of little value in determining whether there has been any movement along the contact. On the west side of the track, there is a little clay at the contact which is probably fault gouge, although this is not positive. In the tipping of the Medina beds from an original horizontal position to their present vertical altitude, one might expect that there would be some slipping at this contact, so that faulting here does not seem to be out of harmony with the idea of a major unconformity rather than a major fault, to account for the variance between the two series of beds.

The failure to find the slightest evidence of faulting at the first exposure described and the continuity of the basal Medinan conglomerate bed in all the exposures has led the writer to his conclusion that the correct interpretation is an unconformity.

There is additional evidence of an extensive erosion interval in the Schuylkill Gap region, as shown by the probable absence at this place of the upper Martinsburg and the lower Medina. The presence of much interbedded bluish gray calcareous sandstone, becoming brown on exposure, in the Martinsburg near the contact suggests the middle member of the formation as it is developed in Northampton and Lehigh counties. If the upper, less arenaceous, member is absent, this may indicate a great amount of erosion before the deposition of the Medina.

Likewise there is a probability that the lower division of the Medina is also absent here. This is suggested by the presence of *Arthrophycus* in the basal strata, whereas in other localities this fossil is found only in the upper Medina. In the Lehigh Gap section there are a few hundred feet of unfossiliferous beds below those that contain this fossil.

Additional Evidence of Taconic Disturbances in Pennsylvania

Two other lines of evidence remain to be considered. The most important is the comparison of the lithologic characteristics of the Ordovician and Devonian shale formations. This comparison can well be made between the Martinsburg of Lehigh and Northampton counties and

the Marcellus-Hamilton shales of Monroe County. The two series consist primarily of argillaceous sediments and interbedded sandstones. White[22] gives the thickness of the Hamilton-Marcellus as ranging from 1,760 to 5,000 feet. The thickness of the Martinsburg is indeterminate, but is probably approximately 5,000 feet thick. The two series outcrop as parallel bands from 4 to 6 miles apart. Lithologically, the two series were so much alike originally that it would seem as though we should find similar metamorphic products if they had both suffered the same deformative movements. This we do not find. The Martinsburg of Lehigh and Northampton counties contains the most valuable slate deposits of the country, whereas the Devonian argillaceous sediments have nowhere been developed into satisfactory slates. On Big Creek near Kresgeville, Monroe County, White says that school slates were at one time manufactured of material from the Marcellus, but that the slate was not durable enough for roofing purposes. Slaty cleavage is common within the Devonian shales of the region, but it is not so well developed nor has sericitization progressed as far as in the near-by Martinsburg.

It may be argued that the deeper burial of the Martinsburg should account for its greater metamorphism, but the difference does not seem sufficiently great to satisfactorily explain the decided difference in their present characteristics. Accepting the figures of thicknesses given by White, the Marcellus beds of Monroe County had a probable cover of 18,000 feet of sediments before the Appalachian Revolution, and the Martinsburg was buried less than 5,000 feet more. Undoubtedly the strong competent beds of the intervening Medina and Oriskany and the Catskill-Pocono had considerable effect in protecting both of the shale bands, but we can not see that either band was favored. The Martinsburg, 5,000 feet in thickness, lay between the massive Cambro-Ordovician limestones and the Medina sandstones, whereas the Marcellus-Hamilton-Chemung shales, aggregating 3,800 feet, lay between the resistant and competent Oriskany and Catskill sandstones.

From whatever angle we view the matter, and making allowance for various factors that may enter into the problem, it does seem that the extreme metamorphism of the Martinsburg, in which even sandstones have well-developed slaty cleavage, and the limited amount of metamorphism of the Marcellus-Hamilton-Chemung indicate a pre-Silurian period of metamorphism. Although of less value, a similar comparison might be made of the Cambro-Ordovician and the Siluro-Devonian limestones of eastern and central Pennsylvania. There is a striking differ-

[22] I. C. White: Geology of Pike and Monroe counties. Pa. Sec. Geol. Survey, Report G6, 1882.

ence in the degree of metamorphism of the two series shown in the marmorization of the calcareous beds and sericitization of argillaceous streaks, and in the almost complete destruction of fossils in the older series.

A second line of evidence is concerned with a comparison of the structures of the Cambro-Ordovician and the Siluro-Devonian sediments, only a few miles apart. It is recognized that there are complicated structures on both sides of Blue Mountain, the Cambro-Ordovician strata lying to the south and the Siluro-Devonian to the north, but it is surely evident to any one familiar with the region that the complexity of structure on the south side of Blue Mountain, which with available evidence baffles solution in many places, whether we are dealing with limestones or shales, is far greater than on the north side. Also, one usually searches in vain for evidences in the sandstones of Blue Mountain of the beautiful folds observable in the slate quarries of Bangor, Pen Argyl, and Slatington. Mr. Behre, who has been studying the microscopic structure of the Martinsburg, has presented detailed evidence along this line. He has shown that there has been a period of intense folding following the orogenic period during which sericitization of the Martinsburg shales was produced. Macroscopic folding in the cleavage planes can also be found in many slate quarries. These vary in size from a fraction of an inch, in what is commonly called "curl," to some that are a foot or more in amplitude. Plainly, these show movement subsequent to the development of slaty cleavage, although how much later can not be determined.

Summary and Conclusions

An attempt has been made to bring together such evidence as is known to the writer of a period of folding and subsequent erosion between the Martinsburg (Hudson River) and the Medina (Shawangunk) in New York, New Jersey, and eastern Pennsylvania. Some of the evidence seems conclusive, but some is only indicative. Plainly, more data must be obtained from a more widely extended area before we should be justified in claiming a great period of mountain-folding at or near the close of the Ordovician, and it is hoped that other contributions to the subject will be forthcoming from persons who are familiar with the problem in other sections.

The evidence presented may be summarized as follows:

1. Definite unconformities have been determined at Rondout and Otisville, New York; Green Pond Mountain, New Jersey, and at Lehigh Gap and Schuylkill Gap, Pennsylvania. Other probable unconformities exist.

Tilting or folding of the Martinsburg (Hudson River) shales and subsequent erosion occurred before the deposition of the Medina (Shawangunk) sandstones and conglomerates. Basal conglomerates are in most cases in contact with the slates.

2. Sericitized shale pebbles apparently derived from the Martinsburg have been noted in the basal conglomerates.

3. The sericitized pebbles are not oriented with respect to each other nor to the bedding planes of the conglomerates.

4. In the Schuylkill Gap region there is some evidence of the absence of the upper member of the Martinsburg and the lower portion of the Medina.

5. The Martinsburg shales are metamorphosed to a far greater extent than the Devonian shales only a few miles away.

6. The structures of the Cambro-Ordovician sediments are far more complex than those of the Siluro-Devonian, and the degree of metamorphism exhibited by the former is far greater than by the latter.

7. Microscopic and macroscopic folds of the cleavage planes of the slates are to be found in many quarries.

Bearing of this Problem on the Location of the Ordovician-Silurian Boundary

In this paper no mention has been made of the recent discussion of the place where the boundary line between the Ordovician and Silurian should be drawn, nor of the dispute concerning the correlation of the beds described. The terms "Shawangunk" of the New York Geological Survey and "Medina" of the Second Pennsylvania Survey have been used throughout. In all probability both of these terms will be abandoned in Pennsylvania, as the result of studies now being made by Dr. George H. Ashley, State Geologist of Pennsylvania, but until the matter has been settled it has seemed advisable to use the old nomenclature.

If the unconformity at the top of the Martinsburg (Hudson River) shales is as important as the evidence presented above seems to indicate, we surely should draw the Ordovician-Silurian boundary line at that point, unless better reasons than those thus far presented are forthcoming. The disturbance responsible for the results described must have extended far beyond the limits of the regions considered, and it is believed that it will be possible to obtain additional data to prove that there was a major disturbance at the close of the Martinsburg period of deposition, such as to warrant the placing of the Ordovician-Silurian contact at the top of the Martinsburg.

Discussion

Dr. Henry B. Kummel: One locality is known in New Jersey where the contact of the Shawangunk conglomerate on the Martinsburg is visible. Here the basal beds of the conglomerate rest upon the beveled edges of the slate. The angular unconformity is not great, viewed either along the strike or down the dip, but there can be no doubt as to the discordance in bedding—a discordance which can be explained only by a certain amount of folding.

The occurrence of some localities where the two formations are apparently structurally conformable does not militate against the assumption of extensive folding previous to the formation of the Shawangunk.

Dr. I. C. White: The Medina formation can be traced southwestward from New Jersey across Pennsylvania and Maryland into West Virginia, and everywhere appears to rest unconformably on the underlying Martinsburg shale, although the exposures are few and far between. One of the best of these in West Virginia occurs in Grant County, seven miles above Petersburg, where the south branch of the Potomac cuts through the great fold of the Wills Creek Mountain anticlinal. Here, according to the observations of Mr. D. B. Reger, Assistant Geologist of the West Virginia Geological Survey, there is a decided difference in the angle of dip of the Martinsburg shale and the overlying gray Medina sandstone.

The three-fold division of the Medina formation from below upward, namely, gray Medina, red Medina, and white Medina, persists from the Delaware Water Gap southwestward across Pennsylvania, Maryland and West Virginia, and Virginia as far as New River, where the gray Medina has dwindled to only two feet in thickness, beyond which it disappears entirely; and the red Medina, filled with *Arthrophycus harlani*, rests directly and unconformably on the Martinsburg shales, according to D. B. Reger. These three divisions of the Medina make up the basal beds of the Silurian, and the line of separation from the underlying Ordovician should be placed at the base of the gray Medina and not at the top of the red Medina, as some geologists have suggested, since the red Medina contains the same fossils as the white Medina above and should not be separated from it, while the gray Medina immediately below the red beds is conformable with the latter and should be included in the Medina series as the basal member of the Silurian.

The Shawangunk conglomerate at Otisville, New York, may represent either the white or gray Medina, but it is certainly of Silurian age.

Dr. George H. Ashley: Having long been a doubter regarding the extent of pre-Medinan folding, feeling that differences of competency

might explain facts described, I was interested this fall to examine the section in the Lehigh Gap. I came away convinced that an angular unconformity existed at that point. There is, however, another problem involved. As described by Dr. I. C. White, the Medina series in Pennsylvania consists of three groups—the Tuscarora or white Medina at the top, the Juniata or red Medina (equivalent to the Richmond of the Mississippi Valley), and the Oswego, or Bald Eagle, or gray Medina at the base. The paleontologists have claimed that the Juniata and Oswego contain fossils that in Europe are classed as of Ordovician age, and that it therefore should be classed as Ordovician. If that is done, the systemic boundary would come not in the plane of the unconformity, but in the midst of the Medina. At present there is a distinct difference in practice in drawing this boundary, as between those who draw the line in the Medina and those who draw it at the top of the Martinsburg.

Prof. JAMES F. KEMP: The unconformity described by Professor Miller continues north into the Hudson Valley and is clearly exposed in not a few localities. The great Catskill Aqueduct, now supplying New York with water, has tunneled through the Shawangunk ridge just north of Lake Mohonk, in the Hudson River slates below the Shawangunk conglomerate. My colleague, Professor Berkey, has illustrated and described many of the features in his Bulletin on the Aqueduct, published by the State Museum. In the Vlightberg, a little ridge north of Rondout and near the Hudson River, one can see in an old cement quarry the Hudson River slates, with an east and west strike and a dip of 45 degrees, running directly into vertical Manlius limestone, which has a strike nearly north to south. The Shawangunk grit has pinched out a few miles to the west. If now we restore the Manlius to a flat condition, we must tip the Hudson River slates up to the vertical, so that two great disturbances at widely separated times are proven.

Mr. H. N. EATON: From my own field observations, it is clear that Doctor Miller's contention for an unconformity at the base of the Medina-Shawangunk is well proved. In some places the contact is covered by only a few feet of talus and one has the feeling that an unconformity exists.

Mr. BRADFORD WILLARD: Shawangunk conglomerate containing *Arthrophycus* is undoubtably basal Silurian. It has been stated that Martinsburg is Normanskill. However, Martinsburg overlies Beekmantown and Jacksonburg limestone—Jacksonburg, believed of Trenton age, and Martinsburg, either above or on shore, equivalent to Jacksonburg. Hence Martinsburg is possibly Trenton or Utica in age and considerably younger than Normanskill in age.

Mr. CHARLES H. BEHRE, JR.: There are three reasons why geologists have frequently failed to recognize the unconformity between the Martinsburg and Shawangunk. These are:

(1) The heavy talus slopes of Shawangunk blocks which conceal the unconformity. Thus, in an area where the contact crosses three quadrangles, it is, to the best of my knowledge, after detailed field-work, seen in but one place.

(2) If, as seems highly probable, the Martinsburg was thrown into well nigh recumbent, isoclinal folds before the laying down of the Shawangunk, then the bedding of the latter should be nearly parallel with that of the former along most of the length of the limbs. Hence the finding in one or two places of *apparent* conformability between the beds above and below the contact does not in the least counteract the evidence in another locality, such as the Lehigh Gap, where there is an angular unconformity visible.

(3) If the Appalachian thrust had been from a direction strikingly different from the Taconic thrust, the cross flexures imposed on the earlier by the later folding would be obvious to the casual observer; but where, as here in Pennsylvania, the folding in both orogenic epochs is similarly directed, only the most detailed work shows that *two* separable periods of mountain-building existed.

Prof. U. S. GRANT: When a very competent stratum and a much less competent one, such as the Shawangunk and the Martinsburg, respectively, are folded together, an apparent parallelism of the formations, which are really unconformable, may result. Such exposures as Doctor Miller describes, in which there is (1) an angular unconformity between the two formations, with no evidence of drag or slickensides, and (2) a definite conglomerate at the base of the Shawangunk, which conglomerate contains differently oriented, slaty pebbles that can be matched in the underlying Martinsburg, are really decisive in determining the relationships of the Martinsburg and the Shawangunk. One exposure of this type is worth a hundred which show parallelism of the two formations.

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SILURIAN ROCKS OF ILLINOIS[1]

BY T. E. SAVAGE

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INTRODUCTION

The writer agrees with Schuchert in referring to the Silurian system only the strata that occur between the top of the Richmond group of the Ordovician and the base of the Manlius formation of the Devonian. A marked sedimentary break is present at the top of the Richmond everywhere in Illinois, and with the exception of the long-lived *Leptæna rhom-*

[1] Manuscript received by the Secretary of the Society December 30, 1925.

boidalis, not a single one of the Richmond species continues into the overlying Silurian strata. As thus defined, Silurian rocks are exposed in Illinois in four rather widely separated areas, which may be referred to respectively as the Southwestern area, the Central-western area, the Northeastern area, and the Northwestern area.

Southwestern Area

Girardeau limestone and Orchard Creek shale

The oldest formations of Silurian rocks in Illinois, and indeed the oldest known in the Mississippi Valley, are the Girardeau limestone and Orchard Creek shale, which are exposed in a few places in the extreme southwest part of Illinois and in adjacent portions of Missouri. The Girardeau limestone is thin-bedded, dark colored, and very brittle and in places contains calcareous shale partings showing numerous fossils. In the lower part this limestone grades downward into a bed of calcareous shale (Orchard Creek shale). Between two and three miles south of the village of Thebes, in Alexander County, a thickness of about 35 feet of Girardeau limestone is exposed in the east bank of Mississippi River, where it is underlaid by a few feet of Orchard Creek shale. About an equal distance north of Thebes a thickness of nearly 18 feet of shale (Orchard Creek), having two-inch calcareous bands 4 to 6 inches apart, underlies a thickness of about 12 feet of Girardeau limestone.

Edgewood formation

At the locality 2½ miles north of Thebes, most of the Girardeau limestone was removed by erosion prior to Edgewood time, and the Edgewood sediments were deposited unconformably upon the eroded surface. The younger formation consists of shaly limestone in the lower part, passing upward into rather thick layers of somewhat granular, oolitic limestone, the total thickness reaching about 14 feet.

Sexton Creek (Brassfield) limestone

Two to three miles northeast of the village of Gale, in the east bank of Sexton Creek, a thickness of nearly 50 feet of Brassfield limestone unconformably overlies the Edgewood formation. The Brassfield limestone in this region consists of dark-colored, dense, mostly rather fine-grained limestone, in layers 4 to 8 inches thick, separated from one another by two- to three-inch chert bands. The faunas of all of these formations have been described and are well known.

Unconformably overlying the cherty Brassfield limestone in this area is a thickness of 20 to 25 feet of fine-grained mottled limestone, in layers 12 to 40 inches thick, containing a small, equivocal fauna, some species of which are distinctly Brassfield forms. It is thought by the writer that this mottled limestone overlying the darker-colored, cherty Brassfield is part of the Brassfield formation.

CENTRAL-WESTERN AREA: EDGEWOOD, KANKAKEE (BRASSFIELD), AND JOLIET LIMESTONES

In central-western Illinois (Jersey and Calhoun counties), there are present Edgewood strata several feet in thickness, succeeded above by rocks representing the Kankakee (Brassfield) formation and a considerable thickness of younger limestone of Niagaran age. The largest continuous exposure of Silurian rocks in this area is at and near the town of Grafton, in Jersey County, where the strata dip gently toward the east, with the result that successively higher layers are encountered at the surface in that direction. The detailed section of strata, beginning one-half mile west of Grafton and continuing to one-fourth mile east of the town, is as follows:

Section of Strata exposed in the Vicinity of Grafton

Joliet limestone.

	Feet
1. Limestone, dolomitic, yellowish gray, in layers 1 to 40 inches thick, containing the fossils *Plectambonites transversalis var. Platystrophia reversata, Orthis flabellites, Calymene niagarensis, Illaenus graftonensis*, and others	45

Kankakee (Brassfield) limestone.

2. Limestone, dolomitic, yellowish brown, in layers 3 to 36 inches thick, containing *Rhinopora verrucosa, Clorinda transversa, Stricklandinia triplesiana, Triplecia ortoni*, and other fossils	26
3. Limestone, dolomitic, yellow to brown, containing numerous shells of *Platymerella manniensis*	¾

Edgewood formation.

4. Limestone, dolomitic, yellowish brown, in layers a few to 18 inches thick, containing *Atrypa praemarginalis* and a few other fossils	20

Farther west and north a greater thickness of Edgewood strata appears below the *Platymerella manniensis* zone of the Kankakee limestone and the thickness of the higher Niagaran strata is much less. In the east bank of Illinois River, in Jersey County, about 5 miles south of the

village of Nutwood and 10 miles northwest of Grafton, the *Platymerella manniensis* zone occurs at the top of the bluff, beneath which is a thickness of 28 feet of yellow dolomite, in thick and thin layers, which are thought to represent the Bowling Green member of the Edgewood formation. Corresponding strata are exposed in the west bank of Illinois River, 8¼ miles south of Hardin, at the Monterey schoolhouse, where the detailed section is as follows:

Section of Strata at Monterey School

Devonian system.

	Feet
1. Limestone, gray, coarse granular, in layers 3 to 9 inches thick, containing *Schizophoria iowensis*, *Spirifer iowensis*, *Pentamerella arata*, and other fossils	6

Silurian system.

Kankakee (Brassfield) limestone.

2. Limestone, dolomitic, yellowish brown, with a few chert bands 2 to 3 inches thick near the top	6
3. Limestone, dolomitic, in layers 3 to 6 inches thick, containing many shells of *Platymerella manniensis*	¾

Edgewood formation.

4. Limestone, dolomitic, yellow, in layers 3 to 12 inches thick, with a few fossils	11
5. Limestone, dolomitic, yellowish brown, in layers 2 to 24 inches thick, containing several fossils	12
6. Limestone, dolomitic, yellow, in layers 3 to 18 inches thick, with a band of chert at the top	11
7. Limestone, dolomitic, yellowish brown, in layers 1 to 12 inches thick, containing a few fossils	9

The Silurian strata here rest unconformably on shale of Richmond age. An outcrop of strata similar to those at the Monterey school occurs along a stream on the south side of the wagon road about three-fourths of a mile southeast of the village of Batchtown, in Calhoun County, where they also unconformably overlie Richmond shale.

On the west side of Calhoun County, Silurian strata are well exposed along a stream which joins Mississippi River about one-half mile south of the village of Hamburg, where the section is as follows:

Section of Strata one-half Mile South of Hamburg

Kankakee (Brassfield) formation.

	Feet
1. Limestone, granular to crystalline, in layers 6 to 12 inches thick, weathering to a pink color and containing numerous shells of *Stricklandinia pyriformis* near the base	2½
2. Limestone, gray, finely crystalline, weathering into layers 2 to 12 inches thick and containing shells of *Pentamerus oblongus*	3
3. Limestone, gray, in a single layer, which weathers to a greenish-color and contains a few fossils	1
4. Limestone, gray, in layers 2 to 24 inches thick, having a slightly greenish color where weathered	5
5. Limestone, gray, containing numerous chert nodules and weathering to a greenish color, with few fossils	1½
6. Limestone, gray, finely crystalline, in layers 2 to 3 feet thick, containing several fossils	6
7. Limestone, gray, crystalline, in layers 6 to 9 inches thick, the middle part containing numerous shells of *Platymerella manniensis*	1½

Edgewood formation.

8. Limestone, dolomitic, yellowish brown, exposed to the level of the water	2

Along a stream in the south part of Hamburg a thickness of 10 feet of gray subcrystalline limestone of Silurian age overlies the layer containing *Stricklandinia pyriformis*. The upper 3 feet of this limestone contains numerous shells of *Pentamerus oblongus* and a few poorly preserved fragments of Orthoceras.

Strata corresponding to the Kankakee (Brassfield) limestone are exposed farther north along the east bluff of Mississippi River as far as Pleasant Hill, in Pike County. The strata between the *Platymerella manniensis* zone at the base and the *Stricklandinia pyriformis* zone at the top furnished many species of fossils, the more common of which are listed in the comparative table on a later page.

Northeastern Area

General Statement

The Silurian rocks in northeastern Illinois occur on the east side of the La Salle anticline and in general dip gently toward the east. The oldest strata outcrop along the west side of this area and successively younger rocks are encountered in an eastward direction. They comprise the Edgewood, Kankakee (Brassfield), Joliet, Waukesha, Racine, and Port Byron formations.

EDGEWOOD LIMESTONE

Early Silurian rocks in this area include the Channahon limestone, which has been shown to be of Edgewood age. The description of this limestone has already been published[2] and the detailed sections will be omitted from this paper.

Above the upper member of the Channahon limestone, exposed near Channahon, there is a concealed zone of about 15 feet, above which there occurs a gray crystalline limestone, containing numerous shells of *Platymerella manniensis*, which marks the basal part of the Kankakee (Brassfield) limestone over the greater portion of Illinois.

Strata corresponding in age with the Channahon limestone are exposed in the bank of Horse Creek one and one-half miles east of the town of Essex, in Kankakee County, and again in an old quarry one mile east of Garden Prairie, in Boone County. Equivalent strata are well exposed again about one mile west and 3 to 4 miles south of the city of Belvidere, in Boone County, where the following section was made:

Section of Strata exposed South of Belvidere

Edgewood limestone.

	Feet
1. Limestone, yellowish gray, somewhat cherty, weathering into thin layers with very rough surfaces and containing the fossils *Atrypa præmarginalis, Schuchertella curvistriata, Platystrophia daytonensis*, and others	6
2. Dolomite, yellowish brown, fine grained, weathering into thin layers, and containing many small geodes	9
3. Limestone, coarse grained, somewhat laminated, containing numerous specimens of *Zaphrentis subregularis*, such as occur in abundance at the Channahon locality	2

KANKAKEE (BRASSFIELD) LIMESTONE

The top of the Edgewood formation is thought to occur a few inches to a few feet below the zone of *Platymerella manniensis* throughout northern Illinois, where an unconformity is usually apparent. The strata above and including the *Platymerella manniensis* zone, up to a plane 1½ to 3 feet above the zone containing numerous shells of *Stricklandinia pyriformis*, have been described as the Kankakee[3] formation and are thought to be of Brassfield age. The upper boundary of this

[2] T. E. Savage: the Channahon and Essex limestones in Illinois. Trans. Ill. Acad. Science, vol. 4, 1912, pp. 97-103.

[3] T. E. Savage: Alexandrian rocks of northeastern Illinois and eastern Wisconsin. Bull. Geol. Soc. Amer., vol. 27, 1916, pp. 316 and 317.

limestone is marked by a smooth, weathered, and much-pitted plane occurring 1½ to 3 feet above the zone of *Stricklandinia pyriformis*. This plane is thought to represent an unconformity. The thickness of the formation ranges from 20 to 40 or more feet.

The entire section of the Kankakee (Brassfield) formation as developed in northeast Illinois is exposed along the Santa Fe Railroad below the Joliet Power Plant, in section 30, township 35 north, range 10 east. A detailed section of the strata exposed at this locality is given below:

Section exposed along the Railroad in Section 30

Joliet limestone.

	Feet
1. Dolomite, brown, in rough-surfaced layers 3 to 6 inches thick, the upper part containing numerous impressions resembling coarse algæ, and many shells of *Pentamerus oblongus* and other fossils	12

Kankakee (Brassfield) limestone.

1. Dolomite, brown, in layers 3 to 7 inches thick	2
2. Dolomite, brown to pink, somewhat granular, containing numerous shells of *Stricklandinia pyriformis*	½
3. Dolomite, crystalline, yellowish brown, in layers 6 to 12 inches thick, in places containing many fossils	5
4. Dolomite, crystalline, yellowish brown, in thin layers containing many shells of *Pentamerus oblongus*	2/3
5. Dolomite, yellowish brown, in very irregular layers 12 to 24 inches thick	14
6. Dolomite, massive, granular, in imperfect layers 6 to 36 inches thick, containing many cavities from which corals have been dissolved	5
7. Dolomite, yellow, with chert bands, containing numerous shells of *Platymerella manniensis*	1

Edgewood limestone.

1. Limestone, dolomitic, yellowish brown, weathering into thin layers having very rough surfaces	5

Strata equivalent to those described from south of Joliet are well exposed in the east bank of Kankakee River between 3 and 4 miles below Custer Park, in Will County. This is the locality from which the name for the Kankakee limestone was taken. The detailed section at this place has been already described.

The more prominent species of the Kankakee (Brassfield) limestone in the Calhoun and Jersey County area and in the northeast Illinois area are listed in the following comparative table.

In this table a cross in column number 2, opposite the name, indicates that the species was found in Jersey and Calhoun counties, in west-central Illinois; and a cross in column number 1 indicates that the species occurs in northeastern Illinois.

List of Species from the Kankakee (Brassfield) Limestone in the West-central and Northeast Illinois Area

Cœlenterata	1 Northeastern Illinois	2 West-central Illinois
Alevolites sp.	x	x
Chonophyllum sp.	x	..
Clathrodictyon vesiculosum Nich. and Murie.	x	x
Diphyphyllum cæspitosum (Hall)	x	x
Enterolasma calyculum (Hall)	..	x
Favosites favosus (Goldfuss)	x	x
Favosites niagarensis (Hall)	x	x
Halysites catenularia Linnæus	x	x
Heliolites sp.	x	x
Lyellia sp.	x	x
Streptelasma hoskinsoni Foerste	..	x
Syringolites huronensis (Hinde)	x	x
Syringostroma sp.	x	x
Molluscoidea		
Atrypa cf. *marginalis* (Dalman)	x	x
Atrypa reticularis (Linnæus)	x	x
Atrypa sp.	x	x
Bilobites sp.	x	x
Camarotœchia acinus var. *convexa* Foerste	x	x
Camaroœtchia whitei cf. var. *præcursor* Foerste	x	x
Clorinda transversa (Savage)	x	x
Dalmanella elegantula (Dalman)	x	x
Dalmanella sp.	..	x
Dinobolus sp.	x	x
Gypidula sp.	..	x
Hebertella daytonensis Foerste	..	x
Hebertella fausta (Foerste)	x	..
Leptœna rhomboidalis (Wilckens)	x	..
Orthis fidbellites (Foerste)	x	x
Pachydictya crassa (Hall)	..	x
Pachydictya sp.	x	..
Pentamerus oblongus (Sowerby)	x	x
Pentamerus sp.	x	x
Phœnopora cf. *ensiformis* (Hall)	x	x
Platymerella manniensis (Foerste)	x	x
Platystrophia daytonensis (Foerste)	x	x
Platystrophia reversata (Foerste)	x	x

List of Species from the Kankakee (Brassfield) Limestone—Continued

	1 Northeastern Illinois	2 West-central Illinois
Plectambonites transversalis var.	x	x
Plectambonites sp.	..	x
Rhinopora verrucosa (Hall)	x	x
Rhinopora sp.	x	x
Schuchertella tenuis (Hall)	x	x
Schuchertella sp.	x	x
Spirifer cf. *radiatus* (Sowerby)	..	x
Spirifer sp.	..	x
Stricklandinia pyriformis (Savage)	x	x
Stricklandinia triplesiana (Foerste)	x	x
Stricklandinia sp.	x	x
Strophеodonta (*Brachyprion*) sp.	x	x
Strophonella daytonensis (Foerste)	x	x
Strophonella cf. *rœmeri* (Foerste)	..	x
Triplecia ortoni (Meek)	x	x
Whitfieldella sp.	x	..
Mollusca		
Amphicœlia leidyi (Hall)	x	x
Cyclonema daytonensis (Foerste)	x	x
Dawsonoceras sp.	..	x
Diaphorostonia niagarensis (Hall)	x	..
Hormotoma cf. subulata (Conrad)	x	..
Orthoceras sp.	x	x
Straparollus sp.	x	x
Arthropoda		
Calymene niagarensis (Hall)	x	..
Calymene vogdesi (Foerste)	x	x
Cheirurus sp.	..	x
Dalmanites cf. *verrucosus* (Hall)	..	x
Encrinurus sp.	x	x
Goldius sp.	x	x
Illœnus near *ambiguous* (Foerste)	x	..
Illœnus daytonensis (Foerste)	x	x
Illœnus madisonianus (Whitfield)	x	x
Illœnus sp.	x	x
Metapolichas sp.	x	..
Phacops cf. *pulchellus* (Foerste)	..	x
Proetus determinatus (Foerste)	..	x

The most of the species marked sp. in the above table are new, but the described forms are most characteristic of the Brassfield formation.

JOLIET LIMESTONE

The name Joliet limestone is proposed to include the strata that occur above the weathered and pitted surface occurring 1 to 3 feet above the zone of *Stricklandinia pyriformis,* up to near the top of the quarry of the National Stone Company at Joliet. The lower part of this formation is well exposed in the vicinity of the Power Plant at Joliet, where it has been described on a former page as the upper member of the section at that place. These lower strata of the Joliet formation outcrop again in an old quarry east of the wagon road, about 1 mile south of Saint Charles, where a 3-inch shale band occurs at the base of the formation and a band containing numerous large shells of *Pentamerus oblongus* occurs about 14 feet higher.

A corresponding portion of the Joliet formation outcrops again on the west side of the wagon road, about one-fourth mile north of the town of Mooseheart. Strata belonging above this *Pentamerus oblongus* zone are well exposed in many quarries in the vicinity of Joliet. There is given below a detailed section of the quarry of the National Stone Company which is representative of those in this vicinity:

Section of the Quarry of the National Stone Company at Joliet

Joliet limestone.

	Feet
1. Dolomite, yellowish gray, in rather thick layers, which weather into layers 3 to 8 inches thick and contain several discontinuous bands of chert in the middle part	48
2. Dolomite, gray to pink, somewhat granular, in rather thick layers with greenish shale partings and containing few fossils. A few thin bands of chert occur in the upper part	32

The limestone exposed at the base of the National Stone Company Quarry at Joliet belong a short distance above the uppermost layers described from the vicinity of the power plant a short distance west of the city.

The rocks quarried by the Lehigh Stone Company 5 miles east of Kankakee belong to the Joliet formation.

The more common fossils collected from the Joliet limestone are listed below:

Fossils from the Joliet Limestone

Cœlenterata:

Favosites sp.

Echinodermata:

Caryocrinus ornatus Say.
Eucalyptocrinus crassus (Hall)
Eucalyptocrinus sp.

Molluscoidea:

Fenestella sp.
Anastrophia internascens (Hall).
Atrypa marginalis (Dalman).
Atrypa reticularis (Linnaeus).
Atrypina disparilis (Hall).
Camarotœchia indianensis (Hall).
Crania cf. *siluriana* (Hall).
Cyrtia cf. *myrtia* (Billings).
Dalmanella elegantula (Dalman).
Leptæna rhomboidalis (Wilckens).
Nucleospira pisiformis (Hall).
Orthis flabellites (Foerste).
Plectambonites transversalis (Wahlenberg).
Rhipidomella hybrida (Sowerby).
Schuchertella sp.
Spirifer sp.
Spirifer radiatus (Sowerby).
Stropheodonta profunda (Hall).

Mollusca:

Cycloceras amycus (Hall).
Dawsonoceras annulatum (Sowerby).
Kionoceras cancellatum (Hall).
Orthoceras sp.
Phragmoceras sp.

Arthropoda:

Arctinurus occidentalis (Hall).
Calymene niagarensis (Hall).
Ceratocephala goniata (Warder).
Cheirurus niagarensis (Hall).
Dalmanites verrucosus (Hall).
Illœnus cf. *cuniculus* (Hall).
Illœnus sp.

WAUKESHA LIMESTONE

In the vicinity of Lemont, a few miles north and east of Joliet, a cherty limestone was thrown out when the drainage canal was dug, and corresponding layers are now being quarried a short distance north of the town. This limestone is thought to correspond to that quarried in the vicinity of Waukesha, Wisconsin, which Chamberlin[4] has called the Waukesha limestone. It is therefore referred to in this paper as the Waukesha limestone. There is no apparent unconformity or break between the Joliet and Waukesha formations, but there is a much larger amount of chert in the form of bands in the latter formation. The Joliet limestone as here defined includes strata lower than any exposed in the vicinity of Waukesha, in Wisconsin.

Strata corresponding with those quarried near Lemont are worked in several quarries near Chicago, a few miles farther northeast, where higher strata in the Silurian section are also exposed.

In the Quarry at Bellewood, Illinois, the following succession was seen:

[4] T. C. Chamberlin: Geology of Wisconsin, vol. 1. 1883, p. 187.

Section of Strata in the Bellewood Quarry

	Feet
Racine limestone.	
1. Dolomite, yellowish, vesicular, crystalline, in layers 8 to 16 inches thick, which break with rough fracture and show very irregular, domelike structures. Casts of corals and crinoids are numerous	25
Waukesha limestone.	
1. Dolomite, in layers 2 to 3 inches thick, alternating with thin bands of chert of about equal thickness	12
2. Limestone, shaly, rather fine grained, containing an occasional chert band 2 to 3 inches thick	8
3. Bed composed of irregular bands of chert nodules, 2 to 3 inches thick, alternating with layers of fine-grained, shaly limestone	6
4. Limestone, shaly, fine grained, in layers 10 to 20 inches thick	4
5. Ledge composed of bands of chert nodules, 2 to 3 inches thick, alternating with irregular layers of fine-grained, shaly limestone	12
6. Limestone, fine grained, with occasional bands of chert	6
7. Limestone, shaly, in thick, rather even layers	13
8. Limestone, light gray, fine grained, in layers 12 to 30 inches thick, without fossils	10

The strata in the lower portion of this quarry are considered the equivalent of those in the lower portion of the quarry at Lemont and of those quarried at Elmhurst, Illinois.

In places the Waukesha limestone contains many corals; especially characteristic are species of *Strombodes, Halysites, and Favosites.* In the northwestern area *Pentamerus oblongus* is very abundant through a thickness of several feet in the upper part of this formation.

RACINE LIMESTONE

The Racine limestone contains numerous domelike structures in which the strata dip steeply in various directions. These peculiar structures are best explained by assuming them to be ancient coral reefs. Many of the coralla are still present and many others have been dissolved out, leaving the rock very vesicular.

The name Racine was given by Chamberlin to rocks of this age that are exposed in the quarries in the vicinity of Racine, Wisconsin. The name is used in this paper to include strata that correspond in age to those worked in the quarry near Racine, Wisconsin, but not to include higher strata which contain many fossils that are characteristic of the Guelph. This limestone is well exposed about one mile south of Lyons, in the east half of section 11, township 38 north, range 13 east, where it is

worked in two or three quarries. The face of the quarry of the Superior Stone Company shows the following section:

Section at the Superior Stone Company Quarry

Port Byron limestone.

	Feet
1. Dolomite, yellow, rather fine grained, in nearly horizontal layers 2 to 6 inches thick, containing very numerous shells of a small Pentamerus, of the *P. compressa* type and shells of 2 or 3 species of Conchidium	12

Racine limestone.

1. Dolomite, yellowish gray, vesicular, coarsely crystalline, in very irregular layers 12 to 30 inches thick, containing casts of numerous crinoids, corals, and other fossils	40+

Waukesha limestone.

1. Dolomite, yellowish gray, in layers 3 to 8 inches thick, with a few chert bands in the lower part	11

The lower chert-bearing layers exposed near the base of the foregoing section probably correspond to the upper chert-bearing horizon in the quarry at Bellewood. On the west side of the quarry are three dome-like structures in the Racine limestone which show local dips as much as 30 to 35 degrees, in different directions. The rock in these domes is very vesicular and appears much fractured and broken, and the irregular dips make it difficult to determine the true thickness.

The quarry of the Federal Stone Company and of the Consumers' Stone Company, about one mile southeast of La Grange, also work the Racine limestone and upper Waukesha strata.

PORT BYRON LIMESTONE

Near the town of Thornton the Brownell Improvement Company has worked a large stone quarry for a number of years. The section at this place shows a considerable thickness of strata that occur above the Racine limestone, for which the name Port Byron limestone is proposed on account of the fact that corresponding strata are well exposed in the vicinity of Port Byron, Illinois. The quarry at Thornton shows local domes in which the strata dip at rather steep angles in different directions. Below is given a detailed section of the quarry face:

Section of Quarry at Thornton

Port Byron limestone.

	Feet
1. Dolomite, gray, rather fine grained, in layers 6 to 24 inches thick, which show very rough surfaces and numerous fucoid markings.	20
2. Dolomite, fine grained, containing chert concretions in irregular bands, alternating with limestone layers 9 to 15 inches thick...	14
3. Dolomite, like the overlying beds, but without chert.....	20+

Racine limestone.

1. Dolomite, dark to gray, hard, crystalline, in layers 12 to 40 inches thick, containing numerous fossils, among which crinoids and corals are common.....	60+

The Racine limestone appears to pass without a distinct break into the Port Byron limestone at this place. The latter limestone contains numerous shells of two species of *Conchidium, Sphærexochus romingeri*, and other fossils which are similar to those in the dolomite outcropping about two miles southwest of Manteno, in Kankakee County. They also are similar to species collected from an old quarry in Chicago Heights, and to many of those occurring in the quarry at Port Byron, on the west side of the State, and which are characteristic of the Guelph formation.

Northwestern Area

GENERAL STATEMENT

The succession of Silurian strata in northwestern Illinois is so similar to that in the northeastern part of the State that the same formations and several of the fossil zones can be traced throughout both areas. This fact, together with the similarity of the Silurian strata in Jersey and Calhoun counties with those of the early Silurian in the northeast part of Illinois, indicates that neither the La Salle anticline nor the Kankakee axis was an effective barrier to the spread of the Silurian seas in this part of the Mississippi Valley.

The Silurian rocks in northwest Illinois occur on the west side of the La Salle anticline and dip commonly toward the west, although dips toward the south are not rare.

EDGEWOOD LIMESTONE

The older Silurian strata in this area are exposed near the east border, but they also outcrop in the east bluff of Mississippi River in the vicinities of Fulton and Savanna.

An excellent exposure may be seen about 7 miles north of Fulton, in the bluff west of Johnson Creek, where that creek emerges on the flood-plain of Mississippi River. The detailed section at this place is as follows:

Section of Strata exposed along Johnson Creek

Edgewood limestone.

	Feet
1. Dolomite, yellowish brown, in layers 2 to 3 inches thick, having very irregular surfaces, and containing a few corals	15
2. Dolomite, brown, in rough layers 2 to 8 inches thick, which in the upper part are interbedded with chert bands 2 to 6 inches thick. A band of chert about 10 feet below the top contained numerous shells of *Atrypa præmarginalis*	45
3. Dolomite, brown, fine grained, in layers 4 to 8 inches thick, weathering into more or less shaly materials. A band near the base contains species of *Zaphrentis subregularis, Whitfieldella ovoides, Strophonella* sp., and *Dalmanites danæ*	15

Strata in this exposure dip gently eastward and are doubtless to be correlated with those exposed southwest of the village of Argo and in a few other places along Mississippi River north and south of Fulton.

KANKAKEE (BRASSFIELD) LIMESTONE

In the river bluff north of Savanna an excellent section of the Silurian is exposed, as follows:

Section exposed in Mississippi River Bluff North of Savanna

Waukesha limestone.

	Feet
1. Dolomite, brown, in thick layers, containing very great numbers of shells of *Pentamerus oblongus* and other fossils	33

Joliet limestone.

2. Dolomite, yellowish brown, weathering into rather thin irregular layers which contain several corals	38

Kankakee (Brassfield) limestone.

1. Dolomite, brown to pink, with a two-inch chert band at the top containing many shells of *Stricklandinia pyriformis*	½
2. Dolomite, brown, weathering into thin, rough-surfaced layers which contain a few chert bands and several corals, stromatoporoids, and other fossils	15
3. Dolomite, yellowish gray, in a single layer, containing several fossils	3½
4. Dolomite, yellowish brown, in layers 2 to 4 inches thick	6

Edgewood limestone.

	Feet
Dolomite, siliceous, strongly iron stained, coarsely crystalline	½
Dolomite, siliceous, containing several small fossils	½
Dolomite, gray to brown, shaly, in layers 6 to 12 inches thick	2

Maquoketa shale.

Shale, bluish gray, with few fossils	22

At the locality north of Savanna the Edgewood limestone furnished the fossils *Zaphrentis* sp., *Schuchertella curvistriata, Dalmanella edgewoodensis, Atrypa præmarginalis, Atrypa putilla, Whitfieldella ovoides, Pterinea elegans,* and *Prætus channahonensis.* The species *Phænopora ensiformis, Phænopora* sp., *Rhinopora verrucosa, Stricklandinia pyriformis, Strophonella daytonensis,* and *Prætus* cf. *determinatus* were obtained from the Kankakee limestone. The Kankakee formation, including the *Stricklandinia pyriformis* zone, is well exposed in many other places in northwest Illinois, as east of Sterling, and near Colita, in Whiteside County; in the Mississippi River bluff north and south of Otter Creek, in the same county, and in the bluff bordering Plumb Creek, northeast of Savanna.

In 1914 the writer[5] recognized the presence of strata of Edgewood and Brassfield age in the vicinity of Savanna, and farther north, in Jo Davies County, at the station of Winston on the Chicago Great Western Railroad, and in northeastern Iowa. Thinking at that time that these strata were deposited in a basin that had a northern sea connection, the writer proposed the name "Winston limestone" to include the rocks there that correspond in age to the Edgewood of southwest Illinois, and the name "Waucoma limestone" for the strata that represent Brassfield time. With a better knowledge of the Silurian, the writer now believes that all of the Alexandrian strata of Illinois and Iowa were deposited in a sea that advanced from the south, and thus belong to the same province as the Alexandrian strata of corresponding age in southwest Illinois; consequently those names are not used in the present paper. Ten years later, in 1924, Ulrich[6] proposed the name "Burroughs dolomite" for the Silurian limestones exposed in the lower part of the bluff at Savanna, Illinois, the fauna of which he states "is decidedly post Richmond; and

[5] T. E. Savage: Relations of the Alexandrian series in Illinois and Missouri to the Silurian section of Iowa. Am. Jour. Science, vol. 38, July, 1914, pp. 28-37.

[6] E. O. Ulrich: Notes on new names in table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin. Trans. Wis. Acad. Sciences, Arts and Letters, vol. 21, July, 1924, pp. 71-107.

it is as clearly older than the Clinton." He considered the Edgewood of Missouri a nearer contemporary of these strata than the Cataract of Ontario.

The strata Ulrich included in the Burroughs dolomite are the same as those the writer in 1914 distinguished under the names "Winston" and "Waucoma" formations, and which in this paper are referred to the Edgewood and Kankakee (Brassfield) limestones respectively.

JOLIET AND WAUKESHA LIMESTONES

In the vicinity of Fulton there is an outcrop of the Joliet limestone that is quite similar to the limestone of this formation exposed in the bluff north of Savanna. Corresponding strata may also be seen in the west half of section 17, township 22 north, range 4 east, Whiteside County. A detailed section at the latter locality is given below:

Section of Strata exposed near Ustick

	Feet
Waukesha limestone.	
1. Dolomite, brown, in thick layers showing numerous dendritic markings, containing few fossils	25
2. Dolomite, brown, in thick layers, containing numerous casts and molds of *Pentamerus oblongus* and many compound corals	20
Joliet limestone.	
1. Dolomite, brown, weathering into rather thin, irregular layers and containing compound corals	30
Kankakee (Brassfield) limestone.	
1. Dolomite, brown, with chert bands, containing numerous shells of *Stricklandinia pyriformis* in the basal part	2½

Strata corresponding with some part of the Joliet and Waukesha formations outcrop again in the river bluff in section 19, and in the northeast quarter of section 23, township 22 north, range 4 east, in Whiteside County. In the old quarry at Fulton and generally in the northwest area *Pentamerus oblongus* has a much greater development and is present through a much greater thickness of strata than in northeastern Illinois. The combined thickness of the Waukesha and Joliet formations is somewhat less than in the northeast area, and farther west, in the quarries near Maquoketa, Iowa, the Waukesha appears to merge more intimately into the overlying Racine formation.

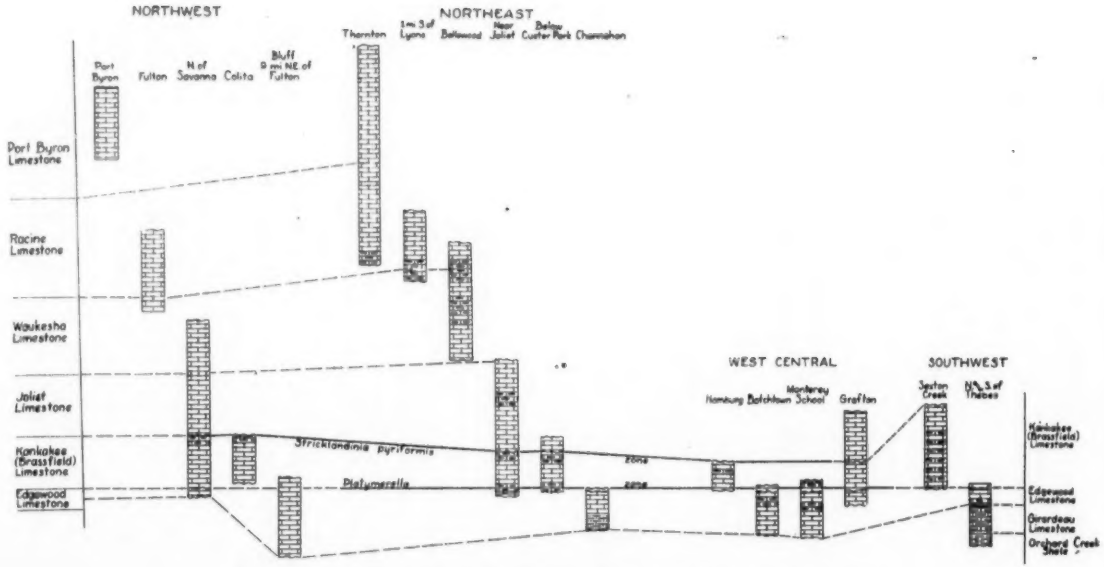

FIGURE 1.—*Columnar Sections of Silurian Rocks in different Areas of Illinois*

RACINE LIMESTONE

Silurian strata belonging to the Racine formation are well exposed in the limekiln quarry at the town of Fulton. This quarry shows about 50 feet of brown, much-weathered dolomite, in layers 2 to 4 feet thick. The lower half contains numerous casts of corals and crinoids similar to those in the Racine limestone at Chicago and in the quarry near Racine, Wisconsin. The Racine limestone outcrops again a few miles south of Fulton, near the northeast corner of section 20, and the northwest corner of section 21, township 21 north, range 3 east, where a thickness of 25 to 30 feet of brown, very irregularly bedded dolomite is exposed. It outcrops again in the vicinity of Mount Carroll in a thickness of 35 feet of soft, brown dolomite, where it dips toward the north and east at an angle of 25 to 30 degrees. It also outcrops about one mile northeast of Malvern, where a thickness of 20 to 25 feet is exposed. In the southeast quarter of section 7, township 21 north, range 5 east, one and one-fourth miles north of the town of Morrison, the Racine limestone is well exposed in the east bank of Rock Creek. Three-fourths of a mile south of the latter exposure and about one-half mile north of Morrison Post Office, the exposed section seen in the bank of Rock Creek is as follows:

Section of Strata exposed along Rock Creek near Morrison

	Feet
1. Dolomite, yellowish brown, containing numerous shells of Dalmanella	9
2. Dolomite, yellow, in layers 9 to 24 inches thick, having thin shale partings	18
3. Limestone, bluish gray, finely crystalline, in layers 12 to 30 inches thick, containing very numerous small brachiopods	6

The strata near Morrison dip eastward at an angle of about eight degrees, and are thought to belong only a short distance above those of the Racine limestone exposed along Rock Creek farther north.

PORT BYRON LIMESTONE

In the new limekiln quarry at the town of Port Byron a thickness of 35 to 40 feet of yellowish dolomite is exposed. The strata dip southeast at an angle of nearly 35 degrees. They are in thin, irregular layers, which, in occasional pockets and along thin bands, are crowded with fossils. Among the fossils collected from the quarry at Port Byron are shells of such species as *Pycnostylus elegans, Pycnostylus guelphensis, Conchidium multicostatum, Trimerella acuminata, Megalomus canadense,*

Monomorella noveboracum, Tremanotus alphæus, Tremanotus chicagoense, Trochoceras desplainense, Trochoceras costatum, which also occur in the upper limestone of the Thornton quarry near Chicago and which are thought to indicate the Guelph age for these strata. The strata in the Port Byron quarry are considered the equivalent of those in the upper part of the quarry at Thornton, Illinois, and the name Port Byron is given to this limestone.

Correlations

The relations of the Silurian strata in the different areas in the State are shown on the accompanying drawing of columnar sections.

The writer's idea of the correlation of the several Silurian formations in Illinois with those of neighboring areas is shown in the accompanying table of provisional correlations. From this table it may be seen that no Clinton strata, such as occur in New York and the Appalachian region, are recognized in Illinois. The Alexandrian strata in the State are all thought to belong to the southern, or Mexican, province. The Joliet, Waukesha, Racine, and Port Byron limestones in northern Illinois represent a rather closely related succession of strata which were deposited in a sea that is thought to have had a northward ocean connection.

Table showing provisional correlation of Silurian in Illinois and neighboring areas.

System	Series		Illinois	Iowa	Missouri	Wisconsin	Michigan	Temiscaming	Hudson Bay	Indiana	Western New York
Silurian	Niagaran	Lockport	Port Byron	Gower (in part)	Bainbridge			Guelph		Huntington	Guelph
			Racine			Racine (including Guelph)	Racine	Lockport	Attawapiscat	Louisville	Lockport
			Waukesha	Hopkinton		Waukesha	Manistique		Ekwan		
			Joliet							Waldron	
		Clinton									Upper Clinton (including Rochester)
											Lower Clinton
	Alexandrian		Kankakee (Brassfield)	Waucoma	Brassfield	Byron	Burnt Bluff	Wabi	Severn	Brassfield	Cataract
			Edgewood (including Bowling Green)	Edgewood	Edgewood	Mayville	Mayville		Port Nelson		
			Girardeau								
			Orchard Creek								

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GEOLOGY OF THE MINGAN ISLANDS[1]

BY W. H. TWENHOFEL

(Presented in abstract before the Society December 30, 1925)

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INTRODUCTION

The Mingan Islands form an island fringe for about 75 miles on the north shore of the Gulf of Saint Lawrence, almost directly opposite the west end of Anticosti. There are twenty-two islands, of which seven may be said to be small and fifteen large. In addition, there are some smaller island bodies, of which some are adjacent to the larger islands and others, as Middle Reef and Mingan Patch, are considerable distances therefrom. Mingan Islands strata also are exposed on the mainland on Point des Morts, Clearwater Point, Ammonite Point, and most, if not

[1] Manuscript received by the Secretary of the Society June 1, 1926.

all, of the shore from Trilobite Bay to Pillage Bay. It also seems probable that strata of the Mingan sequence form the summit of Mount Saint Genevieve, inland from Pillage Bay.

The islands and the several headlands may be placed in an inner and an outer group. To the former belong Harbor, Montange (Romaine), and Montac islands, the inner parts of Clearwater and Ammonite points, Saint Genevieve and Hunting islands, and the mainland adjacent to these two islands.

To the outer group belong the islets of the Parroquet group, Mingan, Inner Birch, Outer Birch, Large, Quarry, Napisca, Quin, Frigla, Eskimo, Green, Gull, Sea Cow, Walrus, Whale, and Saint George islands and the ends of Clearwater and Ammonite points. This outer group of islands is also divisible into an inner and an outer belt. To the former belong Inner Birch, the northern parts of Large Island and Quarry Island, the peninsula on the north end of Napisca Island, Quin Island, the northern half of Eskimo Island, Sea Cow Island, and the northern part of Saint George Island. In the latter are the Parroquet group of islets, Mingan, Outer Birch, the south half of Large Island, most of Quarry Island, the main body of Napisca Island, Frigla Island, the south half of Eskimo Island, and Gull, Green, and Walrus islands and the ends of Clearwater and Ammonite points, Whale Island, and the south peninsula of Saint George Island. As later will be shown, this arrangement arises from the structure and character of the composing rocks.

For the opportunity of first visiting these islands the writer is indebted to the authorities of Peabody Museum of Yale University, who financed the work done there in 1909. The last work done was in 1925, for which opportunity the writer is indebted to a grant from the Research Fund of the University of Wisconsin.

Studies of the Mingan Islands Strata

The strata of the Mingan Islands have been seen by few geologists. They were first studied by James Richardson, who spent a short time there in 1856, at which time he examined the strata of Harbor and Large islands.[2] At some time prior to 1863 Logan or some other Canadian geologist studied the strata of Clearwater Point, as Logan gives a section of the rocks of that point in his Geology of Canada.[3] The writer spent over a week on the islands in 1909, at which time the islets of the Parroquet group, Mingan, Harbor, Large, Quarry, Napisca, Montange, and Eskimo islands were examined and a section was also studied at Clear-

[2] J. Richardson: Geol. Surv. Canada, Sum. Rept., 1857, pp. 239-243.
[3] W. E. Logan: Geology of Canada, 1863.

water Point. The results of this study were given in a summary by Schuchert and Twenhofel.[4] During the summer of 1925 the strata of Inner and Outer Birch, Harbor, Montange, Eskimo, Saint Charles, Hunting, and Saint Genevieve islands and Point des Morts were examined and the strata of Clearwater Point were restudied. The strata of Pillage Bay and adjacent coast and Saint Genevieve Mountain of the mainland were seen from a boat. The fossils from the Mingan strata have been described by Billings.

Rock Structure

The strata of the Mingan Islands are gently inclined in southward directions, the inclinations varying from place to place, but at all places being of low angle. Richardson placed the inclination at 70 to 80 feet to the mile in a direction about south 8 to 9 degrees west. This figure the writer considers may be large, as, for instance, it does not seem that the southward dip on Inner Birch Island much exceeds 40 to 45 feet per mile.

Moreover, the structure is not so simple as it may seem. There are places where the inclinations rise to as great as 3 or 4 degrees and there are also places where the strata are inclined northward. As considerable parts of the geologic section may be concealed, the degree of inclination has considerable bearing on the thickness of strata which may be present. There is little faulting in the exposed strata. What obtains beneath the water is unknown, but there are no facts indicating extensive dislocations. Three small faults were seen on the southwest corner of Inner Birch Island. The throw in each case is southward, the most southern with 4.5 feet, the middle with 2.5 feet, and the northern with 1 foot.

Rock Sections

GENERAL STATEMENT

The sections which have been made on each of the islands are first given and then these are synthesized into one general section for the Mingan Islands. The sections are given from west to east and each is descending.

PARROQUET ISLAND SECTION

The Parroquet Island section is best developed on that one on which the lighthouse is situated. This islet is about 900 feet long and about 250 feet wide. The section is as follows: Number 8 is from a low island southeast of the lighthouse island. It is not known that it rests directly on 7.

[4] Bull. Geol. Soc. Am., vol. 21, 1910, pp. 686-693.

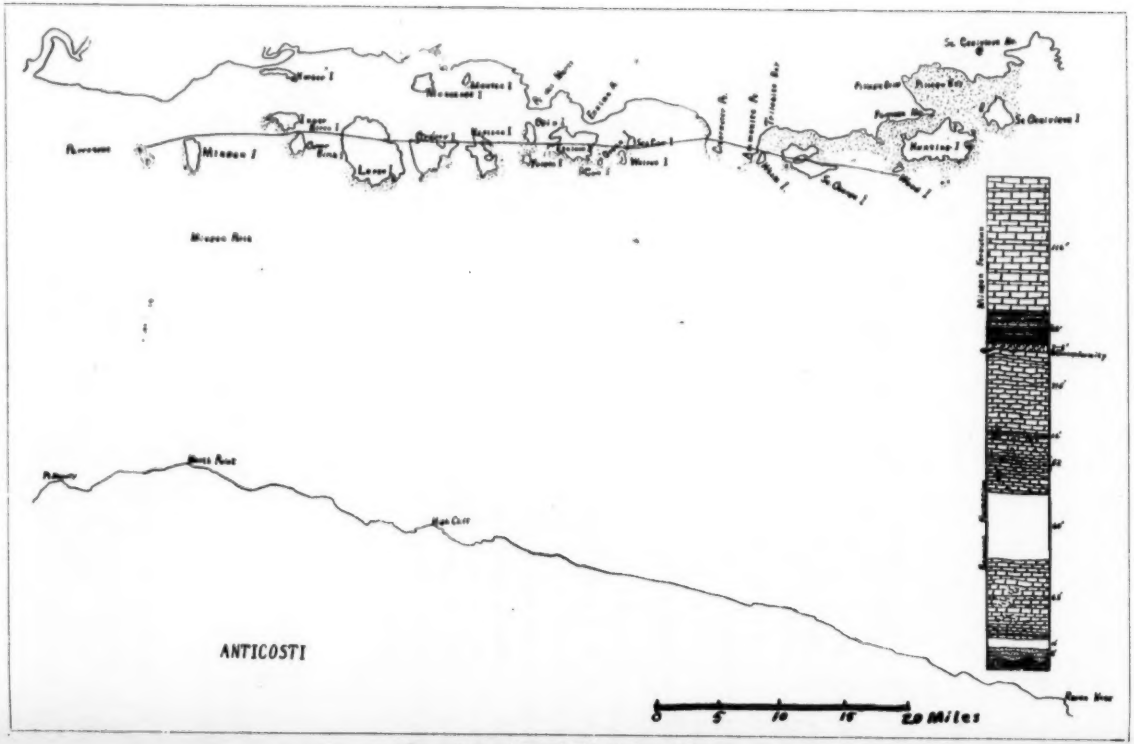

FIGURE 1.—*Map of the Mingan Islands*

	Feet
8. Crystalline, gray to white flinty limestone with conchoidal fracture; contains many clear crystals of calcite	15
7. Limestone, greenish gray, granular, in beds 1 to 3 feet thick; fossils, particularly *Rhynchonella orientalis*, fairly abundant. Only 18 feet exposed, 7 additional feet estimated to the highest part of the island	25
6. Limestone, greenish white, one bed	3
5. Green shale	10
4. Greenish white granular limestone, one bed	2
3. Black carbonaceous shale, a little micaceous near the base; contains a few *Lingulas*	6–7.5
2. Greenish black carbonaceous shale, 6 inches of thin-bedded limestone near the base	5.7
1. Compact gray limestone, exposed on reef and base of cliff	15

MINGAN ISLAND SECTION

The strata of this island lie above those of the Parroquet group.

	Feet
3. Flinty, fine-grained limestone containing many particles of transparent calcite	28
2. Crystalline, fine-grained limestone; contains many small particles of crystalline calcite; many "flower pots" cut on this rock	25–30
1. Coarse-grained, granular limestone containing many particles of white crystalline calcite. In places the rock is sugary and contains geoidal cavities lined with calcite. The bedding is obscure and there are many fossils, particularly corals	25–30

INNER AND OUTER BIRCH ISLANDS

	Feet
15. Gray limestone in 8- to 24-inch beds. The beds do not readily separate	35
14. Gray limestone with well defined, easily splitting parting planes, beds, 4 inches to 2 feet	6.5
13. Dark gray limestone, rough breaking, one bed	1.5
12. Gray, yellow-weathering limestone with splintery conchoidal fracture	2
11. Thin laminated gray limestone with thin bluish green shale partings. Beds range in thickness from 3 to 18 inches. Some beds are much cross-laminated, with length of foresets ranging from 6 to 24 inches	7
10. Grayish blue shale, calcareous	3
9. Dirty gray limestone, thin laminated and shaly	3
8. Impure gray limestone	2.5
7. Interbedded granular gray limestone and greenish blue shale in 3- to 6-inch beds. Thin laminations of shale are in the limestone	2
6. Dark blue, thin laminated shale	1.4
5. Irregularly breaking gray limestone	2

FIGURE 1.—Map of the Mingan Islands

	Feet
4. Dark blue, thin laminated shale	1
3. Gray limestone, well exposed on the wave-cut terrace on the west side of Outer Birch. One bed near the middle is beautifully ripple-marked with symmetrical ripples with wave lengths of 3 to 5 inches and heights approximating one-half inch. Another bed near the middle is mud-cracked with the polygons ranging from 8 to 12 inches in diameter. The lowest strata of Outer Birch Island	8
2. Thick-bedded dolomite with the beds ranging in thickness up to 4 feet; most are 1 to 2 feet. This division contains a bed of dolomite largely composed of *Cryptozoa*, some domes of which are 10 feet in diameter. Secondary domes are developed on the large ones. About 25 feet are exposed and there are probably additional 25 feet exposed in the higher parts of Inner Birch Island before the lowest strata of Outer Birch are reached. These form the highest strata of Inner Birch Island	50
1. Dark gray, yellow weathering, fine grained, splintery dolomite. The strata are laminated but the laminations are not separable. The beds range from about 2 to 6 inches thick and there are occasional thin blue shale partings. There are no evidences of fossils	10

LARGE ISLAND SECTION

The section studied is on west side of the island.

	Feet
18. Flintlike, brittle, compact and bluish gray limestone. The rock contains many small particles of transparent calcite; composes Tower Rock and the south end of the island; about 30 feet exposed; an additional 15 feet estimated. This zone contains many trilobite fragments, flat grastropods, and "*Orthoceras*." Many "flower pots" are present	45
17. Light yellow, compact and brittle limestone, beds 6 to 18 inches thick; no fossils found. The rock of this zone erodes into "flower pots"	40
16. Limestone, some beds sugary, others flintlike; color gray. Beds range in thickness from 3 to 12 inches; no fossils seen. This rock forms "flower pots"	5
15. Gray limestone, some shaly beds; not well exposed and only seen at low tide on the reef (see section in bay on the east side of Large Island)	56
14. Gray sandy dolomite in beds of 3 to 9 inches thickness. Many beds covered with fucoids. *Maclurea* is a not uncommon fossil	10
13. Dull drab and mottled sandy dolomite, beds 3 to 12 inches	10
12. Compact and brittle, drab-colored dolomite. Some beds are locally shaly and many beds are covered with fucoids. The beds range in thickness from 6 to 24 inches	18

	Feet
11. Drab-colored dolomite. Chert nodules occur locally and fucoids occur on the surfaces of some of the beds	6
10. Gray dolomite in which are *Cryptozoa?*	4
9. Gray, compact dolomite	15.5
8. Greenish black shales	1.6
7. Gray, compact, conchoidally fracturing dolomite	12

DEEP BAY ON EAST SIDE OF LARGE ISLAND

	Feet
10. Gray flintlike limestone in thick beds; contains many small, irregular particles of transparent calcite	10
9. Green shale	1.8
8. Gray flintlike limestone	1.5
7. Green shale	1.5
6. Gray, greenish-weathering limestone	1.3
5. Gray, limy, fine-grained sandstone	6
4. Black, green, and dark-gray shale; some beds are sandy	11
3. Quartz sandstone cemented with calcite. The bedding is irregular and indicates deposition in agitated waters. The sandstone contains numerous fragmentary fossils	5
2. Green sandy shale. This rests on an eroded surface	1.5
1. White sandy limestone in 1- to 2-foot beds	8

HARBOR ISLAND SECTION

	Feet
7. Heavy-bedded, mottled, dark-gray dolomite. Chert locally developed in some beds and in places the rock appears as if kneaded. Fossils poor and obscure	20
6. Gray flintlike dolomite	3
5. Heavy-bedded, more or less mottled, dark-gray dolomite. Beds range in thickness from 1 to 32 inches. Chert locally developed in considerable abundance. In some places the rock appears as if kneaded and the bedding in these places is very obscure. Fossils are few and poorly preserved	13
4. Thin-bedded, gray, shaly dolomite and limy gray shale	1.8
3. Hard, dark-gray dolomite in three beds, each about 16 inches thick. The rock is flintlike	4.8
2. Thin-bedded, shaly, gray dolomite	2
1. Coarse, granular, brownish gray dolomite; beds thick; contains some chert and much crystalline calcite in the form of patches and geodes. Fossils are few and poor	13

MONTANGE (ROMAINE) ISLAND SECTION

	Feet
3. Mottled, dark-gray dolomite. Portions of the rock have a kneaded appearance. Chert is locally developed and the rock contains much crystalline calcite. Fossils are few and poor	40
2. Gray, shaly dolomite, base not seen	3
1. Concealed to the crystallines, not over	20

GENERAL SECTION FOR QUARRY AND NAPISCA ISLANDS

	Feet
14. Concealed in the timber on the higher parts of Quarry Island, perhaps	25
13. Flinty gray limestone with many irregularly shaped particles of transparent calcite	30
12. Flinty gray limestone with some beds of granular gray limestone. This zone contains many sponges belonging to the genus *Zittelella*	10
11. Green shale, exposed on the northwestern corner of Quarry Island, but not seen elsewhere	1.5
10. Thin-bedded and flinty dark-gray limestone	1.5
9. Green sandy shale with thin beds of limestone, exposed on the northwestern part of Quarry Island, but not seen elsewhere	1.7
8. Sandy gray limestone, one bed	2
7. Gray and yellow quartz sandstone with a limy cement. Exposed at several places on the north shores of the two islands; usually found at the bases of cliffs	4
6. Black and green sandy shale	7–8
5. Black micaceous shale and gray limestone, not well exposed	10
4. Crumbly and cross-laminated quartz sandstone. Quartz pebbles occur scattered throughout. Many exposures in the bays on the north shores of the two islands. This sandstone rests on an eroded surface	5
3. Compact, gray limestone; bedding not well defined and many beds are wave ripple-marked	6
2. Gray, compact limestone, one bed. The rock has nonseparable bedding planes which are 3 to 6 inches apart	1.5
1. Thin-bedded, somewhat siliceous gray limestone; bedding not well defined	3.8

ESKIMO ISLAND SECTION

	Feet
13. Massive gray limestone, of which one bed is 12 to 13 feet thick. Most beds are of flintlike appearance and the rock breaks with conchoidal fracture. Some beds are wave ripple-marked; others have nodular surfaces. Fucoids, of which some are composed of crystalline calcite, occur on some of the beds. The lower part contains several thin layers filled with small fossils; contains scattered *Maclureas* and orthoceratites in the higher beds. One smooth "*Orthoceras*" with a length of 2 feet was seen. These are the highest strata of Eskimo Island	40
12. Massive-bedded gray limestone	8
11. Interbedded gray shale and gray limestone in 1- to 2-inch beds	4
10. Gray limestone	1
9. Thin, interbedded gray limestone and blue shale. Some of the limestone layers are filled with *Rhynchonella orientalis*	1.5
8. Bluish gray shale and gray limestone	4.5
7. Concealed interval	10

		Feet
Feet	6. Quartz sandstone containing many quartz pebbles, much cross-laminated	4
25	5. Concealed interval on the west side of the island. On the east side of the island this consists at the top of gray shale with thin beds of gray limestone underlain by irregularly bedded gray limestone	10
30		
10	4. Gray dolomite, markedly irregularly bedded; beds up to 3 feet thick. Some beds contain lenses which in some instances resemble pebbles of light-colored dolomite. A bed near the base contains *Cryptozoa* with the domes up to a foot in diameter; most are from 6 to 10 inches in diameter. The top of this division is on the north side of the deep bay on the west side of the island	30
1.5		
1.5		
1.7		
2	3. Bluish gray dolomite in beds up to 18 inches thick; most bedding surfaces irregular and undulating	25
	2. Interbedded blue shale and thin-bedded dolomite	2
4	1. Gray dolomite, exposed on wave-cut terrace	10–15
7–8		
10		

CLEARWATER POINT SECTION

		Feet
	14. Compact and brittle, more or less conchoidally fracturing gray and brownish gray limestone	25
	13. Nodular and shaly gray limestone	10
5	12. More or less nodular green shale	4
	11. Limy gray sandstone	2
6	10. Green shale	0.5
	9. Thin-bedded, limy, gray sandstone	3.5
1.5	8. Gray limestone	20
	7. Thin-bedded, gray limestone and gray shale	2
3.8	6. Gray limestone in 4- to 6-inch beds	1.3
	5. Green shale	2
Feet	4. Compact gray limestone, base concealed	2
	3. Concealed; estimated at 75 feet. In this interval lies the sandstone at the base of the Mingan formation	75
	2. Compact, gray dolomite in thick beds	10
	1. Mottled, dark-gray dolomite in thick beds	40

General Section for the Mingan Islands

MINGAN FORMATION

		Feet
40	16. Flintlike limestone, brittle, compact, conchoidally fracturing. Color bluish gray on fresh fracture, becoming drab gray on exposure. The rock contains many small particles of transparent calcite. This zone makes many "flower pots" and contains trilobite fragments, *Maclurea* and "*Orthoceras*." It makes Tower Rock, on Large Island, and may be seen on Eskimo Island and perhaps on Outer Birch Island. The maximum thickness is believed to be on Large Island, where also the basal portion is concealed	45
8		
4		
1		
1.5		
4.5		
10		

Feet

15. Limestone, interbedded flintlike, compact, drab gray, conchoidally fracturing limestone and minor thicknesses of granular gray limestone. Fossils are generally rare, but occasional laminations occur in which fragments and small forms are common. Many beds are marked with fucoids, of which some are crystalline calcite. On Mingan Island some of the strata which are referred to this zone consist of sugary limestone in which there are many fossils. This zone is characterized by the occurrence of many "flower pots." It has been seen on Mingan, Outer Birch, Large, Quarry, Napisca, Eskimo, and the southern of the small islands adjacent to Eskimo Island. It is also present on Clearwater and Ammonite points and it probably composes parts of Saint George, Walrus, and Frigia islands. Its greatest thickness is on Large Island, where there are..... 51

14. Limestone, more or less granular, but some of compact, flintlike aspect; generally with well defined bedding planes, but many are undulating. In some exposures certain beds of this zone contain many *Rhynchonella orientalis*, and on the east side of Quarry Cove, on Quarry Island, there is one bed containing many *Zittelella*. On Outer Birch Island one layer of the zone is mud-cracked, with the diameters of the polygons ranging from 8 to 12 inches. At the same locality a layer is beautifully ripple-marked with symmetrical ripples of 3 to 5 inches wave length and heights of about one-half inch; also, on Outer Birch Island the upper beds of this zone are cross-laminated with foresets ranging from 6 to 24 inches. Ripple-marking occurs in other exposures. These features show that some of the original sedimentary materials were of sand dimensions. The zone has been seen on Outer Birch, Large, Quarry, Napisca, and Eskimo islands. It is also exposed on Ammonite and Clearwater points and it may occur on Saint George Island. The thickness ranges from..... 10–15

13. Interbedded black and dark-green shale, with occasional beds of limestone up to 2 feet thick. Fossils are few in the shales. They are not uncommon in the limestones. The strata of this zone are exposed on Parroquet Island, north side of Outer Birch Island, in the deep bay on the east side of Large Island, on the north sides of Quarry and Napisca islands, in the bays on the east and west sides of Eskimo Island, on Clearwater and Ammonite points, and some probably are present on Saint George and Whale islands. The thickness ranges from 15 feet on the west side of Eskimo Island to 28 feet on Parraquet Island..... 15–28

12. Sandstone composed of quartz sand and pebbles cemented by calcite. Locally, the zone contains many fossils. It has been seen in bays on the east and west sides of Eskimo Island, on the north sides of Quarry and Napisca islands, and in the deep bay on the east side of Large Island. It may be exposed on the east

Feet

side of Ammonite Point and in the deep bay on the east side of Saint George Island. It is concealed beneath water on Parroquet and Outer Birch islands and it is not exposed on the west side of Clearwater Point. The thickness of the zone ranges from 3–5

Unconformity

ROMAINE FORMATION

Feet

11. Bluish gray dolomite, weathers yellow; most bedding planes irregular and undulating; some are regular and smooth. Many beds are color laminated with different shades of gray. Some beds contain lenses of light-colored dolomite which resemble flattened mud pebbles. One bed near the middle contains many *Cryptozoa*, of which some are up to 10 feet in diameter; most are 6 to 10 inches. This Cryptozoa bed was seen in Inner Birch, Large, and Eskimo islands. The upper part of the zone is exposed on the north end of Quarry and Napisca islands. The thickness of the zone is placed at 55 feet, as such is the thickness on Inner Birch, Large, and Eskimo islands..... 55
10. Compact and flintlike gray dolomite, seen on Large Island..... 16.5
9. Greenish black shale, seen on Large Island..... 1.6
8. Compact and conchoidally fracturing gray dolomite, chert locally developed; seen on Large Island and on the west side of Clearwater Point, where there are 10 feet of compact gray dolomite which are correlated with the strata of Large Island..... 12
7. Mottled gray limestone in thick beds; contains more or less chert; seen only on Clearwater Point and Point des Morts, although some of the strata on the coast between Trilobite Bay and Pillage Bay may belong to this zone..... 40
6. Mostly concealed. The thickness of the concealed strata is uncertain. Logan estimated that between the strata of Harbor and Large islands there is concealed a thickness of 117 feet. This estimate was based on the observed inclination of the strata of the two islands. The estimate may be correct, but, as there is considerable variation of inclination and even reversals, it is possible that the thickness may be much less. I am placing the extent of concealed strata between these two islands at 100 feet, of which it is assumed that 50 feet are exposed on Clearwater Point. This leaves 50 feet which actually may be concealed. The beds of Clearwater Point are thick-bedded, dark-gray dolomite.
5. Flintlike gray dolomite in fairly well defined beds; exposed on Harbor, Hunting and Saint Genevieve islands. The thickness on Harbor Island is..... 23
4. More or less rough and thick-bedded dark-gray dolomite, which in some beds is mottled with patches of darker gray. Some beds are compact and flintlike, light-gray dolomite. Thin beds of

	Feet
gray shale occur at some levels. Chert is locally developed, but not a great deal is present, and vugs and irregular chunks of crystalline calcite occur more or less abundantly throughout. Fucoids occur on the surfaces of some beds. Some portions of the zone appear as if kneaded, and in these portions the bedding is much obscured. This appearance is referred to changes occurring during dolomitization. Beds range in thickness from 1 to 32 inches and the bedding planes are not everywhere well defined. The zone is exposed on Harbor, Montange (Romaine), Montac, Hunting, and Saint Genevieve islands. It may also be seen on the coast between Trilobite and Pillage bays. The greatest thickness was found on Montange Island, where there are...	40
3. Shaly gray dolomite, seen on Montange Island.....	3
2. Concealed, estimated at.....	10
1. White quartz sandstone on the east side of Pillage Bay.....	8
0. Pre-Cambrian crystallines.	

Strata higher than that of zone 16 of the general section probably occur on Mingan Patch south of Large Island. This has not been seen except with field glasses. It appears that the rock consists of limestone.

Correlation

For the present it is not desired to depart from the statement of Schuchert and Twenhofel,[5] by whom the strata of the Romaine formation were tentatively correlated with the interior Beekmantown and Division D 4 and all of Division E of the Lake Champlain sequence and those of the Mingan formation with the upper Chazy and Lowville of the New York section. Until all the collections have been carefully studied, it is premature for any modification of that statement.

Physiography of the Mingan Islands

The Mingan Islands and Anticosti Island, to the south, are the unsubmerged summits of three cuestas, of which two form the Mingan Islands and the third Anticosti Island. The southern of the Mingan cuestas is double ridged. The most northern of the inner lowlands forms the channel between the inner group of islands and the mainland and is partly filled by the deposits forming the coastal plain. The relative weakness of the sandstones which lie at the base of the Mingan section is thought to be responsible for this lowland area. It seems to be lowest adjacent to the islands, and this is thought to have arisen from erosion having moved southward down the surface of the crystallines, the sand-

[5] Bull. Geol. Soc. Am., vol. 21, 1910, pp. 686-693.

stone being cut out, thus undermining the dolomites and forming the steep cliffs characteristic of the north sides of the islands.

The second inner lowland lies between the inner and outer groups of islands, and it seems probable that it owes its origin to the presence of a zone of weak rock holding the position of the concealed part of the section. However, this is entirely supposition, as there is no evidence, beyond the fact of the erosion, that the strata of this part of the section is composed of rock readily yielding to erosion. The double ridge of the southern cuesta is due to the weak zones lying immediately above the disconformity between the Romaine and Mingan formations. The double ridge is well shown on Eskimo island by an east-west depression across the island, whose termini are the bays on the east and west sides, by the deep bay on the east side of Large Island, by indentations in several others of the islands, and the channel between Inner and Outer Birch islands.

The third inner lowland is due to the erosion of the strata in the concealed interval between the Mingan Islands and Anticosti Island. It is inferred that something like 1,600 to 1,700 feet of strata are concealed beneath the waters of the channel north of Anticosti, and of these strata nothing is known beyond the fact that a part is composed of black bituminous shale, as many fragments of such shale have been found on the north side of Anticosti for a distance of about 50 miles from the west end. They are found in largest quantity adjacent to the top of the north-south trending divide noted below. This inner lowland is thought to owe its greater width to two causes, namely, the zone of easily eroded strata is thicker and the streams which produced the erosion were larger, and instead of flowing as many small streams, crossing the cuesta in as many places, flowed as two single streams along the foot of the north-facing escarpment. The thickness of the strata forming the Anticosti cuesta compared to the thickness of the strata responsible for the Mingan cuestas is thought to be responsible for the former not having been cut through by the forming streams which obviously crossed the Mingan cuestas in many places. It may be inferred that in most instances the inner lowlands of the Mingan cuestas are due to lateral tributaries rising in part in these lowlands and flowing into streams which took their origin on the crystalline areas to the north. The erosion responsible for the lowland between the Mingan Islands and Anticosti Island was largely accomplished by two streams whose divide extended from Parroquet Island, in the Mingan group, to North Point, on Anticosti. The western of these two streams was short and flowed around the west end of Anticosti to empty into the Saint Lawrence. The eastern of the two streams was

much longer and flowed along the north side of Anticosti for nearly the entire length of the latter, finally flowing around the east end of Anticosti to reach the Saint Lawrence.

The surfaces of the Mingan Islands, particularly the larger islands, are beautifully terraced, and many of the terraces are backed by wave-cut cliffs similar to those of the present coast. Where the rocks of the islands consist of those of zones 14, 15, and 16 of the general section, the inner margins of the terraces are characterized by the presence of "flower pots," or sea stacks, which are similar to those now being formed where the waves are eroding these rocks[6] (figures 2 and 3).

FIGURE 2.—*An ancient Sea Stack*

One of the "flower pots," with its base 28 feet above the surface of the present wave-cut terrace, in the northwest corner of Outer Birch Island.

On Outer Birch Island terraces have been measured at elevations above the present wave-cut terrace, as follows: 16.5 feet, 22 feet, 28 feet, 38 feet, and 50 feet. Each of these terraces is well preserved, each has a cliff or steep slope at its back, and most have "flower pots." "Flower

[6] It should be stated that there seems to be no other agent operative in these islands which is competent to form the "flower pots." The work of frost is extremely important in this region and its effects may be seen on all exposed rocks which are not being eroded by other locally more important agents. However, frost action tends to form a rounded surface covered with sharp-edged fragments, and this process is now reducing the "flower pots" to that condition. Wind action may produce similar forms, but many of the "flower pots" are in timber, and, as all are in some way associated with terraces, it seems impossible to refer their origin to any agent other than wave action.

pots" on Outer Birch Island, whose elevations were determined, have their bases at 12.5, 28, 34, 43, 56, and 81 feet above the present wave-cut terrace. The 28-foot terrace on Outer Birch Island has a small natural bridge in the sea cliff on the northwest corner of the island. On Inner Birch Island two terraces were seen, one 12 feet above the present wave-cut terrace and one 25 feet above. Terraces were measured on Eskimo Island as follows: 10 to 12, 18 to 20, 33, 44, and 88 feet above the present wave-cut terraces.

FIGURE 3.—*One of the "Flower Pots"*

This view was taken on the southeast corner of Outer Birch Island. The "flower pot" has its base 35 feet above the level of the present wave-cut terrace. This level is shown on the adjacent rocks, which constitute the ancient terrace. The cliff from which erosion removed the stack is to the left.

From the figures obtained, it seems probable that there is one terrace on each of the islands whose elevation above low-tide level is about 12 feet, another at about 28 feet, one around 35 to 36 feet, one at 45 to 50 feet, and two others with elevations approximating 80 to 90 feet. The slight differences in elevation of the terraces from place to place arises from differential accumulation of vegetable matter upon them, from the

extent of erosion on the outer margin of the terrace as the one next below was being developed, and the original position of the terrace with respect to sealevel. The terrace at 28 feet, on the northwest corner of Outer Birch Island, had its elevation determined at its cliff margin, as a mere shelf is all that remains of the terrace at that place.

East of Eskimo Point to Clearwater Point the coast consists of high cliffs of sand and silt, which seem to have been deposited in marine waters and whose summits formerly were the bottom of the sea. The surface on the cliffs is an essentially level plain, which near Clearwater Point has an elevation between 110 and 115 feet above low tide, thus indicating the former submergence of the region to a somewhat greater depth. If the sea should now rise to that elevation, there would be little of the Mingan Islands which would escape submergence.

It is not known when the major outlines of the terraces on these islands were formed, but the details certainly seem to have developed since the retirement of the ice-sheet. This seems to have covered every one of the islands, as shown by grooves, striæ, and erratics.

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STRUCTURAL STUDIES IN SOUTHERN NEVADA AND WESTERN ARIZONA[1]

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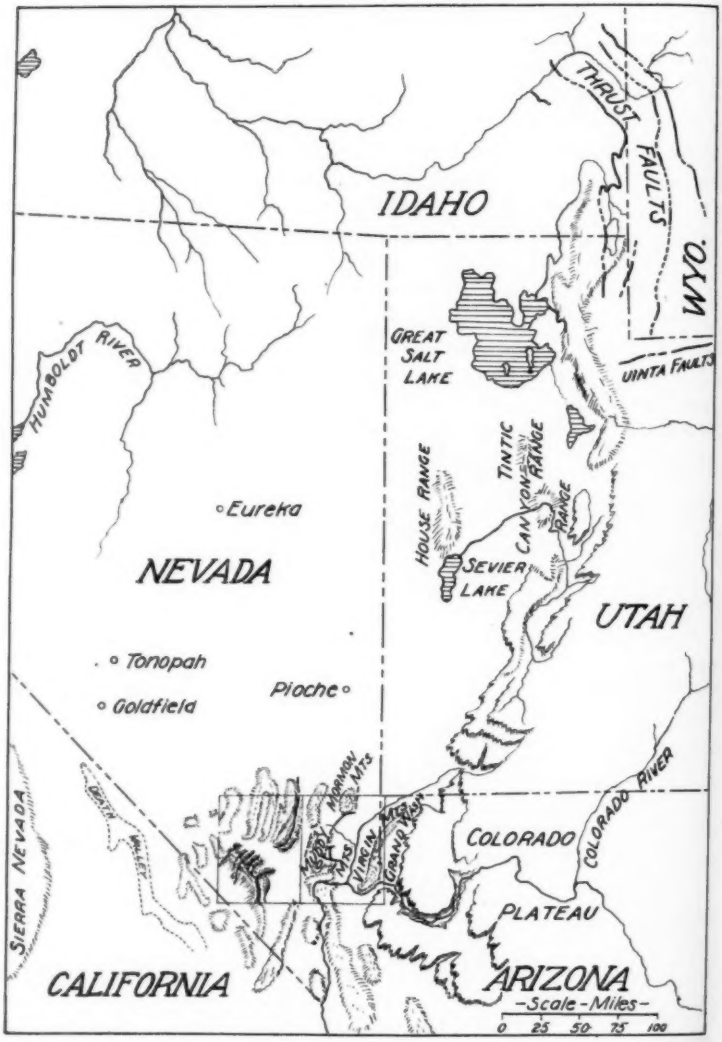

FIGURE 1.—*Index Map showing Positions of Saint Thomas and Las Vegas Quadrangles and of various Features mentioned in Text*

See also figure 3. Outline of the plateau front taken largely from Lobeck's physiographic diagram of the United States.

Introduction

Grand Wash, a tributary of Colorado River in northwestern Arizona, lies in a wide valley whose position is determined by a zone of profound faulting. This valley marks throughout its length a sharp and definite boundary between two major physiographic and structural provinces. East of the valley the Grand Wash Cliffs rise precipitously, as a pair of giant steps, to an elevation averaging 4,000 feet above the valley floor. These cliffs form the abrupt western limit of a great tabular mass, the Shiwits division of the Colorado Plateau, in which the stratified rocks are nearly horizontal over a wide area. West of Grand Wash Valley and reaching into southern Nevada lies the Virgin Range, a complexly broken fault block, in which the same formations exposed in the Grand Wash Cliffs are tilted at high angles. Continuing to the west, other ranges structurally similar to the Virgin Range alternate with wide debris-filled valleys. This region is a part of the Basin Range System defined and described by Gilbert.

Four seasons of field study in the region have revealed a complexity of structure in some of the ranges apparently not suspected in earlier reconnaissance work. During 1919, 1923, 1924, and 1925 the stratigraphy and structure of the following eleven contiguous ranges were examined: Virgin, Muddy, Mormon, Arrow Canyon, Dry Lake, Las Vegas, Spring Mountain, Sheep, Desert, Pintwater, and Spotted. These ranges are included for the most part in the Saint Thomas and Las Vegas quadrangles as mapped topographically by the U. S. Geological Survey. Each of these quadrangles measures a full degree of latitude and longitude and their combined area exceeds 7,600 square miles. The study also extends beyond the limits of these quadrangles to the east, north, and west. The Muddy, Spring Mountain, Desert, Pintwater, and Spotted ranges were studied and mapped in considerable detail. In other ranges geologic mapping was carried far enough to permit the construction of representative structure sections. Such sections are necessarily interrupted by the wide valleys, within which no structure of bedrock formations can be determined.

Perhaps the most striking result of the work is the discovery of major thrust-faults, which trend generally north-south and dip westward. These thrusts represent the earliest severe deformation of the Paleozoic and Mesozoic rocks of the region. Later normal faults broke the crust into a mosaic of blocks. A brief description and preliminary analysis of the principal structural features will be attempted in this paper.

Topography and Drainage

The dominant trend of ranges and of the major structural valleys is generally north-south, in keeping with the common pattern of ranges and basins in the greater part of Nevada. However, there are important exceptions to the rule, some of the major topographic units trending northeastward, others northwestward. There is an obvious general relationship between the topographic pattern and the regional structure. However, the effects of successive structural events are superposed, many structural features have been practically obliterated by erosion, and for any range it is not safe to infer any particular type of structure merely from the topography.

Each range is surrounded by wide structural valleys, which, with the associated fan slopes, have a larger total area than the ranges. Many of the valleys are basins receiving interior drainage, and it is evident that others were of this character until a very recent geologic date. At present there is exterior drainage in a part of the area, controlled by Colorado River, which cuts across the southern part of the Saint Thomas quadrangle, with a course at right angles to the trend of the ranges. It is joined by Virgin River, which follows the old structural depression between the Virgin Range on the one side, the Mormon and Muddy ranges on the other. These two rivers have their source beyond the limits of the Basin Range province. Muddy Creek, a tributary of Virgin River, is fed by large springs near the Arrow Canyon Range. In the vicinity of these permanent streams the old basin deposits are dissected by a network of drainage channels, dry during most of the year.

Elevations in the area range from a minimum of 700 feet on Colorado River to nearly 12,000 feet in the highest peak of Spring Mountain. The distribution of relief is highly irregular. Many ridges and knobs barely show above the floor of waste, whereas the larger ranges rise thousands of feet above the bordering valleys. Many of the mountain borders are high and precipitous, but others merge gradually into long slopes of debris. In general the higher ranges are extremely rugged, although some preserve remnants of flattish erosion surfaces.

Stratigraphy

Pre-Cambrian rocks

Rocks of pre-Cambrian age are exposed in large areas of the Virgin and Mormon ranges and to a more limited extent at the mouth of the Grand Canyon, in Boulder Canyon, and at the west base of Frenchman

Mountain, in the Las Vegas quadrangle (see figure 3). They consist of complex gneisses and schists, invaded by more than one generation of granite. Quartzites interbedded with mica schists and garnetiferous gneisses indicate that a large part of the metamorphic complex was originally sedimentary. The trend of schistosity varies widely, from north-south to nearly east-west, but the northerly trends predominate. These rocks are sharply separated from Cambrian strata by a remarkably plane surface of unconformity.

PALEOZOIC ROCKS

General statement.—Sedimentary formations of the Paleozoic systems have a total thickness in the Virgin Range appreciably greater than in the Grand Canyon region, and the rate of increase in thickness accelerates westward. Comparison of columnar sections along a west-east line emphasizes the differential subsidence during the Paleozoic in the eastern half of the Cordilleran geosyncline (figure 2). This differential sinking of the pre-Cambrian floor continued until near the close of Pennsylvanian time. Formations of Permian and upper Pennsylvanian (?) age continue from the Plateau Province into the Basin ranges with essentially uniform thickness.

Cambrian rocks.—The change in thickness of Paleozoic formations from east to west is illustrated particularly well by the Cambrian strata. Noble's sections at the Bass Trail, 90 miles east of the Grand Wash Cliffs, show the following succession:[2]

	Feet
Upper Cambrian:	
Muav limestone	473
Middle Cambrian:	
Bright Angel shale	391
Tapeats sandstone	328
Total	1,192

In the Virgin Range the thickness of the Upper Cambrian limestone is more than 1,000 feet, whereas the typical Bright Angel shale and Tapeats sandstone together total about 600 feet. In the Mormon Range the sandstone and shale units have about the same thickness, and although the limestone is considerably thicker the total Cambrian section does not measure 3,000 feet. In the Desert Range, only 50 miles west of the Mormon Mountain sections, the total thickness of exposed Cam-

[2] L. F. Noble: A section of the Paleozoic formations of the Grand Canyon at the Bass Trail. U. S. Geol. Surv. Prof. Paper 131-B, pp. 26-27.

brian is approximately 14,000 feet, of which 8,500 feet belong in the Lower Cambrian.

A similar change in thickness is seen by comparing sections somewhat farther south. At the west base of Frenchman Mountain the Bright Angel shale and Tapeats sandstone are exposed in a typical section, totaling 550 feet. The sandstone rests directly on the Archean complex. In the northwestern part of Spring Mountain, 40 miles west of Frenchman Mountain, T. B. Nolan measured over 16,000 feet, probably nearly all Cambrian, as follows:

	Feet
Upper Cambrian limestone and dolomite (probably including some Ordovician at the top)	5,000
Middle Cambrian shale and sandstone with thin beds of limestone and quartzite (including typical Bright Angel shale)	1,500
Lower Cambrian sandstone and shale with thin quartzite layers	2,100
Lower Cambrian quartzite and subordinate sandstone	3,200
Lower Cambrian (?) shale with thin-bedded quartzite and sporadic dolomite (base not exposed)	4,500
Total	16,300

At the Groom mine, which is in an unmapped area 75 miles north of Spring Mountain, a continuous tilted section affords a magnificent display of the Cambrian rocks. As in the ranges farther south, the base is not exposed, but the visible section is approximately as thick as that of Spring Mountain. Thus the thick development of these strata continues in a generally north-south direction. The thickness of the Cambrian section in these ranges is astonishing, as it represents an increase by more than 10,000 feet in a present horizontal distance of 50 miles or less.[3] The greater part of the increase comes from addition of Lower Cambrian clastic formations, which are not represented in Frenchman Mountain, the Mormon Mountains, and farther east.

Post-Cambrian Paleozoic rocks.—The Ordovician is represented in the Spring Mountain Range by several hundred feet of limestone with subordinate limy shale, overlain by a thin formation of quartzite. In the ranges north of the Las Vegas Valley all members of the system are more fully developed and have a total thickness of 2,000 feet. Thin Silurian dolomite is recognized locally in Spring Mountain and is continuous, with somewhat greater thickness, in the ranges to the north. Ordovician and Silurian strata have not been identified east of the Las Vegas quadrangle.

[3] This distance was greater originally, as there has been considerable fore-shortening by thrust-faulting.

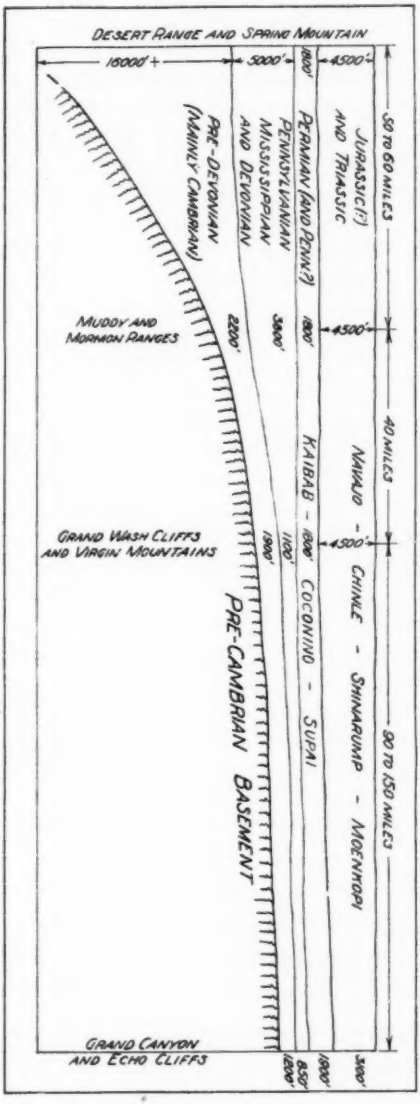

FIGURE 2.—*Diagrammatic Section to illustrate Increase in Thickness of sedimentary Formations restored from Colorado Plateau*

Vertical scale grossly exaggerated.

Devonian limestone and dolomite are recognized as far east as the Virgin Range and probably extend into the plateau. Limestones of lower Mississippian age do not vary greatly in thickness over the entire area; but the upper Mississippian and Pennsylvanian section thickens greatly between the mouth of the Grand Canyon and Spring Mountain. The Supai (Pennsylvanian and Permian ?) and Kaibab (Permian) formations are remarkably uniform in all sections (see figure 2). The intervening Coconino sandstone, which is very thin in the Grand Wash Cliffs, loses its identity farther west.

The total Paleozoic section varies from east to west as follows: Grand Wash Cliffs (Gilbert's section), 4,800 feet; Mormon Mountains, 7,800 feet; Spring Mountain (base of section not exposed), 22,000 feet.

MESOZOIC ROCKS

Within the area under consideration the youngest Mesozoic formation is a thick cross-bedded sandstone, probably equivalent to all or part of the Navajo-Todilto-Wingate succession, of Jurassic (?) age.[4] This sandstone and older Mesozoic formations (the Chinle, Shinarump, and Moenkopi, in descending order) are surprisingly uniform in character and thickness on the plateau and in the Basin ranges. In Spring Mountain, in the Muddy Mountains, and in southwestern Utah the total thickness of these units ranges from 4,500 to 5,000 feet. Mesozoic strata are largely removed from the plateau in the vicinity of the Grand Canyon, but they can be traced continuously around the north rim of the canyon country, and there is an evident gradual decrease in thickness of pre-Cretaceous sediments eastward. The lower part of the Moenkopi is of marine origin, but the higher formations are entirely continental.[5] In the entire region the contact between the Lower Triassic and the Permian is a surface of unconformity which does not cut through the underlying Kaibab limestone except very locally in the Spring Mountain area.[6]

TERTIARY ROCKS

Strata of Cretaceous age have not been found in any part of the area and the earliest Tertiary sediments probably are of Miocene age. These are peculiar basin deposits, locally very thick, predominantly clastic, but

[4] These formations are unfossiliferous and lie beneath marine Upper Jurassic rocks. There is a possibility that they may include rocks of Upper Triassic age.

[5] The marine Jurassic of southern Utah is believed to be later than any of the rocks considered here.

[6] C. R. Longwell: The pre-Triassic unconformity in southern Nevada. Am. Jour. Sci., vol. 10, 1925, pp. 93-106.

including considerable limestone and also unusual minerals, such as magnesite and colemanite, in important quantities. These deposits, which rest with profound angular unconformity on the older rocks, are especially widespread and thick in and around the Muddy and Virgin ranges. A coarse deposit at the base has been named the Overton fanglomerate, and the higher sediments, containing carbonates, borates, and other precipitates associated with large quantities of volcanic ash, are known as the Horse Spring formation.[7] Strata containing white limestone and volcanic ash also form extensive outcrops around the Las Vegas, Pintwater, and Spotted ranges, and in all probability these are to be correlated with the Horse Spring formation. On the basis of its peculiar lithology this formation is correlated tentatively with the Barstow, Esmeralda, and Siebert formations of eastern California and southwestern Nevada. These formations are all regarded as probably of upper Miocene age.

The Overton and Horse Spring sediments are in turn separated by a large angular unconformity from basin deposits of probable Pliocene age, which have been disturbed only locally, and therefore lie almost horizontally in the intermont valleys. In the Virgin and Muddy valleys these deposits, known as the Muddy Creek formation, have been dissected to a depth of several hundred feet. Basic lava flows are included in the formation.

QUATERNARY DEPOSITS

The intermont valleys and the piedmont slopes have thick accumulations of detritus, mainly unindurated, ranging in texture from coarse boulders in alluvial fans to fine silt in playas and in floodplains. Similar deposits are still forming, locally at a rapid rate. In Grand Wash Valley basaltic lavas of post-Pliocene age are in part buried by later gravels.

STRUCTURAL SIGNIFICANCE OF THE STRATIGRAPHIC RECORD

It is apparent that the early structural history of this region was characterized by broad warping movements and not by orogenic disturbances. In the Lower Cambrian epoch there was active subsidence of the Cordilleran geosyncline to receive shallow-water sediments almost as thick as the combined formations of all later Paleozoic time. Evidently the rate of sinking during the Lower Cambrian varied, as fine clastics and even limestones are intercalated with heavy deposits of conglomeratic and arkosic sandstone. Probably the feldspathic material

[7] C. R. Longwell: Geology of the Muddy Mountains, Nevada, with a section to the Grand Wash Cliffs, in western Arizona. Am. Jour. Sci., vol. 50, 1921, pp. 52-54.

was derived from the pre-Cambrian rocks east of the geosyncline. Apparently the pre-Cambrian floor was either warped down quite sharply or faulted on the east side of the trough, as the Lower Cambrian rocks do not extend as far eastward as Frenchman Mountain. An alternative hypothesis might be that there was down-faulting in the trough and complete removal of any Lower Cambrian sediments to the east before or during the Middle Cambrian epoch.

Subsidence of the geosyncline was continuous or recurrent until late Pennsylvanian time. Beginning with the Middle Cambrian, however, the seaway spread widely eastward into the present plateau country, and in the Upper Cambrian the hinge marking differential subsidence shifted to a position near the eastern boundary of the Basin Range Province. The red Supai formation marks the disappearance of the hinge and the advent of remarkably uniform sedimentation throughout the Grand Canyon country and southern Nevada.

At the end of the Paleozoic era there was regional emergence, followed by shallow but very widespread erosion. Triassic time began with broad resubmergence, but the shallow sea was soon filled, and continental sedimentation, probably at a low elevation, continued into the Jurassic.

The thick sedimentary plate was first broken by orogenic forces in the late Mesozoic or more probably in the early Tertiary. The basin sediments of Miocene (?) time were deposited, and these in turn suffered deformation by both folding and faulting. Normal faulting on a grand scale blocked out the basins in which the Pliocene (?) sediments accumulated and established the ranges in essentially their present positions. Faulting has recurred in post-Pliocene time, but it has not appreciably changed the relation of ranges and basins as they existed during the Pliocene.

Structure

Thrust-faults

General statement.—Block-faulting on a large scale is an obvious characteristic of this entire area. In general each range appears to be a well defined block of tilted strata, or a combination of such blocks, each exhibiting approximate uniformity of dip. Many of the mountain fronts are fault scarps in various stages of modification by erosion, and there is compelling inference that the large intermont valleys represent fault blocks relatively depressed and now concealed with debris from the ranges. These general relations were recognized by Gilbert, who included the Spring Mountain Range among those briefly described in his original dis-

FIGURE 3.—*Chart of the principal Faults now known in the Las Vegas and Saint Thomas Quadrangles and along Grand Wash, in the Mount Trumbull Quadrangle*

The chart is incomplete, especially for the Sheep, Las Vegas, Arrow Canyon, and Mormon ranges, the northern part of the Virgin Range, and the southern part of the Muddy Range. Dotted lines inclose individual ranges and associated foothills. Thrusts are shown by special convention (see legend), and in addition parts of overthrust plates are indicated by parallel lining. Known faults whose exact positions are largely concealed with alluvium are indicated by broken line. Upthrow and downthrow sides of faults indicated by U and D, respectively. Positions of a few faults near mouth of Grand Canyon taken from geologic map of Arizona.

cussion of the Basin Range System.[8] Other ranges in the northern part of Las Vegas quadrangle are better illustrations of the type discussed by Gilbert.

The evidence for Basin Range structure is necessarily in large part physiographic, as most of the critical faults are hidden by debris. Step-faulting along the borders of ranges, apparently sympathetic with major faults in the valleys, gives important corroborative evidence. In general, however, the ranges show a complex pattern of older faults whose direct topographic expression has been nearly or quite obliterated by erosion. Many of these are normal faults, with various trends; but of outstanding importance is a series of thrusts, some of which can be traced long distances in spite of much later fragmentation. As these thrusts are clearly the oldest important structural features of the region, they will be given first place in description. They are indicated by special convention on the fault chart (figure 3), and in addition parts of the overthrust blocks are designated by diagonal lining to show the continuation of thrust-zones in some places where the actual traces of the faults have been concealed by younger movements.

The Muddy Mountain thrust.—Throughout its entire length the Muddy range shows evidence of major thrusting movement directed from west to east. In the northern part the overthrust[9] mass has been largely eroded away and the thrust zone is recognized chiefly by severe overturning of the overridden[9] strata. Farther south a large portion of the overthrust plate has been preserved and is well exposed for study. Near the west side of the range "windows" have been eroded through the plate where it was domed sharply. Around the periphery of the "windows" and below isolated remnants of the thrust plate the actual thrust surface can be studied. This surface is especially well defined, as the rock beneath is the massive Jurassic (?) sandstone, with its conspicuous coloring, whereas the overthrust plate is of dark limestones and dolomites of Paleozoic age. As the beds above and below the thrust are essentially parallel and the stratigraphic throw is approximately 10,000 feet, it is certain that the movement had its origin considerably farther west than any of the present outcrops. Toward the east the thrust plate is clearly a unit, although it has been broken by several large normal faults. As one of these later faults forms the present eastern boundary of the

[8] G. K. Gilbert: The Basin Range System. U. S. Geog. and Geol. Surv. West of 100th Mer., vol. 3, 1875, pp. 21-42.

[9] Such terms as "overthrust" and "overridden" are used here strictly in a descriptive sense to designate parts of a thrust fault or zone. There is no intention to imply active movement in the sense of overthrusting to the exclusion of possible underthrusting.

plate, presumably the original front of the thrust was still farther east. The distance between the easternmost and westernmost outcrops of the overthrust mass is approximately 18 miles, and obviously this distance is a minimum measure of the horizontal displacement.[10]

This extensive remnant of the thrust plate terminates northward at a steep fault, on which there has been movement with an important horizontal component, as indicated in the strong eastward bend in the strike of adjacent formations on the north. Because of the marked difference in the character of the thrust to the north and south, it is believed that this east-west fault served to accommodate differential movement at the time of thrusting. To the north the zone is complicated by imbricate structure, and the principal thrust has a westward dip of 30 degrees or more. The Supai and Kaibab formations are sharply overturned in front—that is, to the east—of the thrust, and the consistent structure of these formations, continuing through a line of isolated hills north of Muddy Creek, furnishes a logical basis for projecting the Muddy Mountain thrust northward. The interpretation is further justified by the presence of a thrust in the southern end of the Mormon Range, directly in line with the row of isolated hills to the south.

In the Mormon Mountains the thrust-zone is highly irregular. At the southern end of the range there is a well defined thrust, dipping steeply westward, with lower Paleozoic limestones overriding Pennsylvanian and Permian formations. The strike turns strongly to the northeast, and several miles farther north the outcrop ends abruptly at a large fault trending nearly east-west, with large downthrow on the south. Several miles to the east and directly north of the east-west fault there are thrust relations of a peculiar character. Two isolated hills are capped with Cambrian limestone and quartzite, which obviously have been pushed eastward over pre-Cambrian gneiss and schist along a flat surface. The sedimentary rocks are greatly brecciated and contorted, although the bedded structure is still recognizable. West and northwest of this location the same Cambrian formations are dropped down against the gneiss and schist on a steep fault with westward dip and north-south strike. It is believed that these relations indicate thrusting over an erosion surface of pre-Cambrian rocks, after which the north-south normal fault developed, and nearly all of the overthrust mass

[10] Additional discussion of the Muddy Mountain thrust is given in "The Muddy Mountain overthrust in southeastern Nevada" (Jour. Geol., vol. 30, 1922, pp. 63-72) and in "Geology of the Muddy Mountains, Nevada" (Am. Jour. Sci., vol. 51, 1921, pp. 39-62).

has been eroded from the upthrow side. It is probable, therefore, that the sedimentary section near the east side of the range was involved in thrusting, and this interpretation is indicated in figure 3. In adopting this interpretation it is necessary to assume that the thrust cuts downward into the pre-Cambrian rocks at no great distance west of the north-south fault, as there is no indication of shearing between the sedimentary shell and the pre-Cambrian basement in the exposures of the latter near the center of the range. Furthermore, the relation of the erosion thrust to the large thrust-zone farther south is not apparent.

Ignoring the obscure features discussed above, the known extent of the Muddy Mountain thrust-zone along the strike is approximately 50 miles. Apparently there is no major thrust between the Muddy Mountains and the Plateau front, although a small block of Kaibab limestone (Permian) has been pushed over the Jurassic (?) sandstone in a low part of the Virgin Range directly east of Muddy Creek. Probably this is a minor feature developed locally in front of the Muddy Mountain thrust.

The Las Vegas thrust-zone.—The Spring Mountain Range has a number of important thrusts, which give the range an imbricate structure. At least one of these faults can be traced southward into the Goodsprings area, where a similar imbricate zone has been studied and described by Hewett.[11] Outcrops of the Spring Mountain thrusts end northward at the wide debris-filled Las Vegas Valley; but north of this valley two similar thrusts are exposed, chiefly in the Las Vegas Range. One of these faults, which turns from an east-west to a north-south strike, can be followed on good evidence to the north boundary of the map. By filling in the gap of several miles made by Las Vegas Valley we may consider the thrusts of the Las Vegas and Goodsprings areas as a unit zone traceable nearly 100 miles along the strike. This is the largest group of thrusts so far discovered in southern Nevada. For convenience in this general discussion, the part of this belt of faults included in the Las Vegas quadrangle will be referred to as the Las Vegas thrust-zone. Its development is shown best in the Spring Mountain Range, where the width of the imbricate zone exceeds 30 miles.

Spring Mountain thrusts.—It is obvious from inspection of the map (figure 3) that most of the thrusts exposed in Spring Mountain strike almost at right angles to the axis of the range. Because of this fact the high part of this range furnishes an excellent opportunity to study the details of faulting and to observe the relation between the various

[11] D. F. Hewett: Manuscript in course of publication by U. S. Geological Survey.

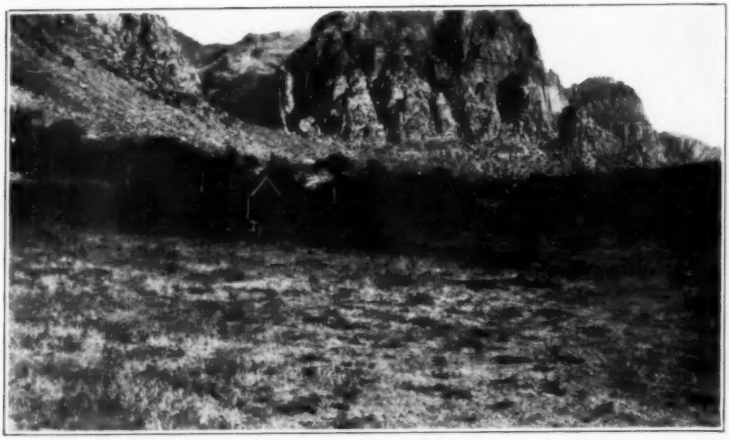

FIGURE 1.—CLIFFS OF THE JURASSIC (?) SANDSTONE

The cliffs extend parallel to the outcrop of the Keystone thrust. A small part of the Cambrian thrust plate shows above the head of the canyon in the left portion of the view. View looking northwest. Photograph by T. W. Stanton, U. S. Geological Survey.

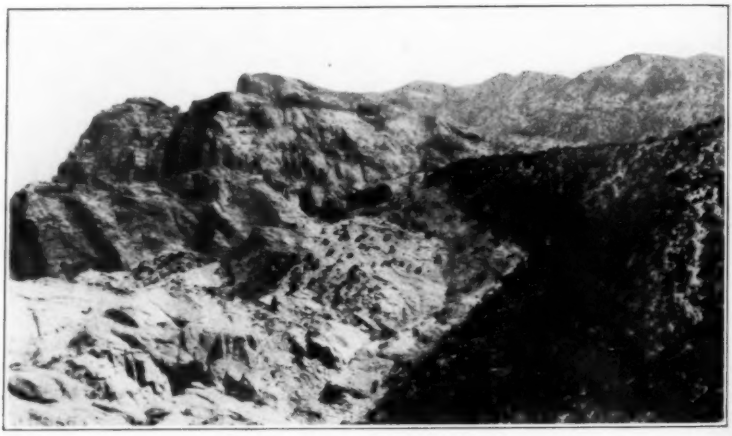

FIGURE 2.—OUTCROP OF THE KEYSTONE THRUST

The outcrop is above the cliffs shown in figure 1. Cambrian thrust plate at the right, covered with pinyon and juniper; the Jurassic (?) sandstone at left. View looking south.

VIEWS OF THE KEYSTONE THRUST

structural features in this wide belt of thrusting. The foothills offer less satisfactory exposures, but it is possible to trace individual thrust-faults 25 miles or more from one flank of the range to the other. All of the thrusts have suffered offsetting by steep intersecting faults, but in general it is not difficult to match the dismembered parts.

The most conspicuous structural feature of the range is the Keystone thrust, which extends northward into the Las Vegas area from the Goodsprings district, where it was mapped and named by Hewett,[12] As shown in the chart (figure 3), the outcrop of this fault within the Las Vegas quadrangle has a trend slightly west of north for a distance of about 12 miles, then turns abruptly northeastward and approaches Las Vegas Valley with a course only a little north of east. Along the south leg of this inverted "L" the approximate course of the fault is marked by a line of bold cliffs, 1,000 to 2,000 feet high, formed by the massive Jurassic (?) sandstone beneath the thrust (plate 17, figure 1). The outcrop of the thrust, above and a short distance west of the cliffs, has a sinuous course in response to crosscutting valleys. This course is easy to trace, even from a distance, because of the fact that juniper and pinyon trees grow profusely on the dolomite and limestone of the overthrust plate and sparsely or not at all on the Jurassic (?) standstone in front of the contact (plate 17, figure 2). Near the edge of the cliffs the thrust surface is nearly parallel to the strata, both below and above, the dip of which averages about 10 degrees westward A short distance west of the cliffs the dip of the thrust and of the beds in the overriding mass steepens rather abruptly to 30 degrees. The dolomite and limestone at the base of the overthrust plate is of Upper Cambrian age, and the stratigraphic throw at the outcrop of the thrust is approximately 12,000 feet.

East of the sharp bend in its outcrop the character of the thrust is considerably changed. The same formations—Upper Cambrian and later—are involved in the overthrust plate, the strike of the strata bending sharply to parallel the new course of the fault. However, the dip of these formations and of the fault beneath averages 35 degrees to the north-northwest, and the thrust overrides a series of tilted fault blocks, remnants of an older flat overthrust, whose stratigraphic throw is comparable to that of the Keystone fault. An important north-south fracture breaks and offsets both thrust plates. For this part of the area, therefore, the following succession of events is clearly recorded: (1) development of an important flat thrust—to be spoken of hereafter as the Red Spring thrust—with indeterminate but obviously large hori-

[12] D. F. Hewett: Op. cit.

zontal displacement; (2) normal faulting on fractures striking northwestward, breaking the thrust and tilting the blocks to the northeast; (3) erosion removing much of the faulted plate; (4) development of a second thrust (the Keystone) overriding fragments of the first; (5) later normal faulting. These relations are indicated in figure 3.

A steep thrust-fault, approximately parallel to the southern leg of the Keystone thrust and about 5 miles east of it, brings the Supai formation (Pennsylvanian and Permian ?) against the Moenkopi (Lower Triassic), involving a stratigraphic throw of nearly 2,000 feet. This fault also appears to be the northward continuation of a thrust mapped by Hewett in the adjoining quadrangle.

Farther northwest in the range five thrust-faults are spaced at intervals ranging from 1½ to 6 miles and averaging slightly more than 3 miles. All of these faults are relatively steep, the dips ranging from 25 degrees to 55 degrees and averaging about 35 degrees. One, the Wheeler Pass thrust, has a nearly constant strike averaging north 45 degrees east. One other, the Lee Canyon thrust, can be traced entirely across the range; but near the summit its course changes abruptly, like that of the Keystone thrust, from nearly north to northeast. Two other thrusts, in front of the Lee Canyon fault, definitely end near the axis of the range against a steep transverse fracture. The outcrop of the fifth thrust fault, northwest of the Lee Canyon thrust, is limited to the high part of the range, possibly because faulted portions are completely concealed on the fan slopes. In most of these faults the Upper Cambrian limestone is brought against Pennsylvanian. The largest stratigraphic throw, approximately 12,000 feet, is shown by the Wheeler Pass thrust, in which Lower Cambrian quartzite rests on Pennsylvanian limestone (figure 4).

Thrusts north of Las Vegas Valley.—Two well defined thrust-faults cut through the Las Vegas Range. The larger is very well exposed directly north of Gass Peak, and therefore it will be called the Gass Peak thrust. Like the Wheeler Pass thrust, it dips about 25° degrees to the north and west and exposes Lower Cambrian quartzite against Pennsylvanian limestone. Five miles to the southeast is the smaller Marble Quarry thrust, which can be traced only a few miles, its outcrop disappearing at the borders of the range; but so far as it is visible it is closely parallel to the Gass Peak thrust. Both of these faults approach Las Vegas valley with a course nearly straight west, or in the Gass Peak thrust even slightly north of west. Traced in the opposite direction, the outcrops curve into a northeast strike, and the Gass Peak fault

assumes a course nearly straight north. In the northern part of the map the exact position of this fault is concealed by debris, but its continuation and approximate position are determined by the consistently overturned attitude of Pennsylvanian strata in the low northward extension of the Las Vegas range. It is possible that the Marble Quarry thrust also continues to the north, but if so it is completely hidden in the valley west of the Arrow Canyon Mountains.

No other thrusts of importance are exposed in the ranges north of Las Vegas Valley. There is some evidence of intense compression at the western border of the Pintwater range, in the northern part of the quadrangle; but if an extensive thrust ever existed in that locality the

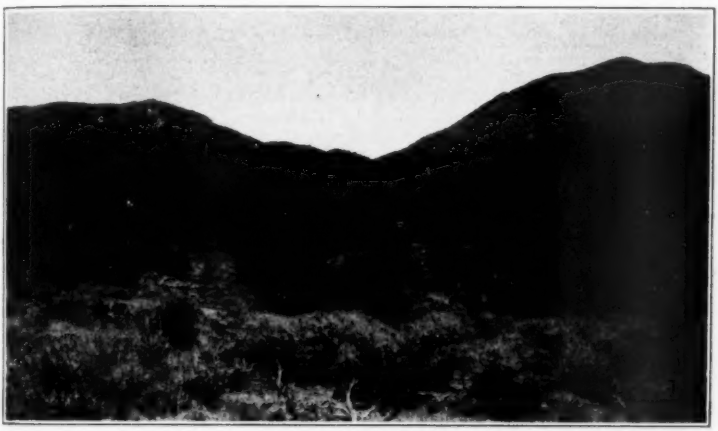

FIGURE 4.—*View of the Wheeler Pass Thrust*

The view is looking northeast from point 1, figure 3. Outcrop of the thrust in lowest part of saddle. Thrust dips 30 degrees to left. Pennsylvanian limestone right of saddle. Lower Cambrian quartzite at left. In foreground, Upper Cambrian limestone thrown down on fault trending northwest at base of ridge. This fault offsets the thrust to point out of view on right.

plate has been faulted down and completely buried by debris. There has been some local thrusting in the southern part of the Spotted range, but nothing of a major character, so far as can be judged from present exposures.

The Dry Lake thrust.—Although much of the actual structure is concealed, it is apparent that either a thrust or a sharply overturned fold parallels the west side of the Dry Lake Mountains. This small range is made of Pennsylvanian strata, which for the most part lie almost flat. Along the entire west border, however, the strata are bent up sharply

and turned past the vertical toward the east, indicating a strong thrusting movement from the west. A short distance west of the range older Paleozoic strata, exposed in isolated hills, dip moderately westward. These relations are so typical of the steeper thrust faults that the existence of the Dry Lake thrust is assumed confidently, although no part of the actual fault is exposed. The strike of the upturned Pennsylvanian strata indicates that the trend of the fault is about north 20 degrees east. There is no basis, of course, for assuming the continuation of the thrust beyond the ends of the range.

The weight of circumstantial evidence for this fault may be more readily appreciated after the following discussion of typical thrusts.

The thrusts in cross-section.—Cross-sections of the different thrusts, or of any one thrust at various localities, show differences in structural detail, as might be expected. However, certain general forms of cross-section are very common, and if unimportant modifications are neglected a few type examples may be used to illustrate all of the thrusts in the area. The most obvious basis of classification is the angle of dip, and accordingly a division will be made into *flat* thrusts and *steep* thrusts. No sharp line separates these two classes, as the Keystone fault is seen to change from the flat to the steep type both along the strike and in cross-section. However, it will be helpful to consider separately those faults in which a considerable part of the thrust surface had an original inclination of 10 degrees or less from the horizontal. This group includes the Muddy Mountain, Keystone, and Red Spring thrusts. All others are included in the steep group, as in these the parts now exposed appear to have developed with a dip of 25 degrees or more.[12]

The steep thrusts are illustrated very well by the Lee Canyon thrust as exposed on the northwest side of Charleston Peak (plate 18, figure 1). The fault has an average dip of 35 degrees to the northwest, and the Upper Cambrian strata on the hanging-wall side dip in the same direction, at a slightly smaller angle. On the northwest slope of Charleston Peak Carboniferous strata in an overturned position dip 50 degrees to 60 degrees in the direction of the fault. These beds were doubled back sharply beneath the thrust, as indicated in plate 18, figure 2. Directly under Charleston Peak are beds high in the Pennsylvania, dipping 20 degrees northwest. As these beds are followed down the dip along the north

[12] The terms "high angle" and "low angle" are avoided in this discussion, as some writers have applied these terms to faults with dips above and below 45 degrees, respectively. In that sense most of the thrusts in the area discussed here would be classed as low angle faults, as very few have been found with a dip higher than 40 degrees.

FIGURE 1.—VIEW ALONG LEE CANYON THRUST

The view is looking southwest from point north of Charleston Peak. Outcrop of thrust in saddle near right. See figure 2 for explanation.

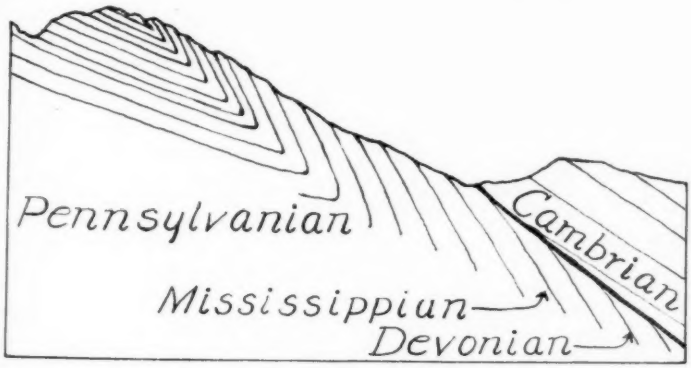

FIGURE 2.—SECTION UNDER SKYLINE OF THE VIEW ABOVE

The section shows the structure above and below the thrust. Minor breaks and irregularities are omitted.

CROSS-SECTION OF THE LEE CANYON THRUST

side of the peak they are seen to turn up and back through an angle of 140 degrees. Progressively older strata are encountered down the slope, and directly in front of the thrust contact is the massive lower Mississippian limestone, bent back in the same manner as the thinner Pennsylvanian beds and reduced to considerably less than its normal thickness. Canyons crossing the fault reveal Devonian formations at a lower level, with the same attitude.

The following features in connection with the thrust are noteworthy:

(1) The strata overridden by the thrust are broken sharply back at an acute angle, with essentially no curvature. The beds are badly brecciated and fractured near the apex of the angle.

(2) Near the thrust contact the upturned and overridden beds are minutely shattered, though still coherent. Probably the marked thinning of the beds in this position was accomplished in the main by granulation and slicing.

(3) There is some local replacement of calcite by dolomite in the overridden limestone strata near the thrust, but this alteration is not extensive. Apparently it is confined to layers especially susceptible to the change or to small zones of unusual brecciation and shearing.

(4) Rocks in the overthrust plate are extremely shattered through a considerable thickness. Secondary dolomite is extensive, but very irregular in distribution. At some points practically all of the overriding strata in a thickness of several hundred feet have been completely dolomitized. Commonly a selective action is apparent, indicating greater susceptibility to the change in certain beds or formations. Some layers containing abundant trilobite remains appear to be almost immune to the alteration even near the thrust.

(5) There is little evidence of underdrag in strata of the overthrust plate corresponding to the overdrag in the overridden strata.

(6) The overridden mass stands much higher in the present topography than the overthrust plate, although the rocks in the latter are normally of greater resistance. This is a common feature of the steep thrusts, even where massive quartzite has been thrust over limestone. The explanation lies in the weakening through extreme shattering of the overriding mass.

A modification of the typical cross-section described above is shown by the Wheeler Pass thrust at the summit of the range (figure 4). Carboniferous strata in front of the thrust are not overturned, but show very moderate drag effect. Evidently these beds were sheared cleanly at this point. At other localities along the same thrust, however, both

northeast and southwest of the summit, the overridden beds are strongly overturned. In fact, except for the Wheeler Pass section, the steep thrusts in the area have this extensive overturning as a characteristic feature.

In a study of the flat thrust faults the Keystone thrust is especially instructive because it indicates the probable relationship between the steep and flat types. In the southern part of the quadrangle the dip near the present front of this thrust averages 8 degrees, and the thrust surface is nearly parallel to the bedding below and above. A few miles to the north erosion has cut the thrust front farther back, and deep canyons run eastward directly across the fault, giving long transverse sections in which the thrust surface is seen to steepen from 10 degrees at the front of the cliffs to 30 degrees near the heads of the canyons. In this change of dip the thrust cuts across the bedding in the Jurassic (?) sandstone. It is probable, therefore, that with further erosion the Keystone thrust will come to resemble the steeper faults discussed above; and it is quite possible that at an earlier date some of the steep faults—for example, the Wheeler Pass and Gass Peak thrusts—extended farther eastward than their present outcrop, with a flat dip.

It appears significant that all of the flat thrust plates in the area have ridden forward on the Jurassic (?) sandstone, which was the youngest formation in the region at the time the thrusts were developed. This fact, in connection with the cross-section of the Keystone fault, suggests that the larger thrusts emerged at a fairly steep angle, and of necessity flattened abruptly, to coincide with the surface of the land. There is definite evidence that the visible portion of the Red Spring thrust plate was driven forward over an erosion surface. At many localities a coarse conglomerate, containing pebbles and large boulders obviously derived from the formations in the overthrust mass, lies directly below the thrust surface, filling depressions in the Jurassic (?) sandstone. Many of the pebbles have been sliced repeatedly by shearing and nearly all are badly crushed. Apparently these fragments were eroded from the front of the thrust plate, deposited in front of it and overridden as the movement continued.

The presence of Cambrian sediments thrust over pre-Cambrian crystalline rocks in the Mormon Range was mentioned previously. Such relations also suggest thrusting over an erosion surface, but under conditions quite different from those postulated above.

The southern part of the Muddy Mountain thrust shows the most extensively developed flat plate in the area. Presumably the front of

this thrust moved at least 18 miles over an erosion surface. The maximum possible thickness of the overthrust plate, near the west side of the present range, was approximately 2 miles, and there is little apparent divergence between the thrust surface and the stratification. These facts suggest several problems, all of which merit more extensive discussion than can be attempted in this paper. A few will be mentioned briefly:

(1) What are the mechanical conditions of a movement in which a plate so thin suffers displacement through a distance at least nine times its maximum thickness? Certainly the nearly horizontal attitude of the thrust is a favorable factor. The erosion surface may have been uneven in detail, but, as the massive Jurassic (?) sandstone is friable and weak, minor irregularities on a dissected surface would offer little resistance to the overriding mass. According to Lawson's computations,[14] a movement so extensive could not occur as an overthrust even under the most favorable conditions; but no discussion of the general principles will be undertaken here.

(2) If the flat attitude resulted from emergence of a steeper thrust on an erosion surface, would not the strata of the overthrust plate dip forward toward this surface rather than parallel it? This would be a logical expectation, provided the thrust developed as a simple shear cutting nearly horizontal beds at a large angle. A common feature of the steep thrusts has an obvious bearing on this point. As noted previously, the beds above the Lee Canyon, Wheeler Pass, and similar thrusts dip nearly parallel to the fault surface. Evidently, then, if the thrust plate in riding forward should encounter a flatter surface, a necessary adjustment of the plate would keep the strata essentially parallel to the fault. The section of the Keystone thrust, showing curvature forward from steep to flat dip, illustrates this adjustment. The close parallelism of strata and fault surface in the steep thrusts is in itself a matter that merits further study.

(3) Do the thrusts reach downward into the crystalline basement or are they confined to the sedimentary shell? Reasoning from the testimony of certain other regions, we may suppose that the pre-Cambrian rocks are involved. However, in this area all of the direct evidence is of a negative character, for of the many large thrusts not one exposes the old crystallines in the hanging wall. This fact may be entirely fortuitous, but other considerations have a bearing on the problem. Let

[14] A. C. Lawson: Isostatic Compensation considered as a Cause of Thrusting. Bull. Geol. Soc. Am., vol. 33, 1922, pp. 337-352.

us assume that the flat Muddy Mountain thrust developed from a steeper fault, as suggested above; that this fault at the time of its inception was a plane cutting at a uniform angle across the sedimentary section and that the fault emerged at the old erosion surface near the west border of the present Muddy range. Such a fault, projected downward with a dip of 30 degrees, would reach the crystalline floor in a distance of 4 miles; or if the dip were only 20 degrees, it must intersect the crystallines at a distance of 6 miles. But we have seen that the front of the thrust plate was displaced at least 18 miles to the east from the assumed position of the steep fault, and yet the base of the plate in the weternmost exposures consists of sedimentary beds in a nearly horizontal position. Therefore one of two conclusions seems inevitable; either the assumed steep thrust turns to a nearly horizontal attitude before it reaches the base of the sedimentary section or the steep fault does not exist, and the thrust projects downward west of the Muddy range at a consistently low angle not exceeding 6 degrees.[15] The first of these conclusions is favored by consideration of the steep thrusts and particularly by the testimony of the Keystone thrust. In either case thrusts of the Muddy Mountain type involve superficial deformation on a large scale.

Steep fractures related to the thrusts.—The steep east-west fracture bounding the flat Muddy Mountain thrust plate on the north has been mentioned. Important horizontal movement occurred along this fracture, the block on the south moving eastward, as is indicated clearly by remarkably pronounced drag effects. It is believed that this steep fault was formed during some phase of the thrusting movement in response to differential horizontal stresses. According to this interpretation, the fault is a *flaw* (*Blatt* of Suess), or, in the terminology of certain British geologists, a *tear fault*.

Similar features are recognized in other parts of the area. In the heart of the Spring Mountain Range a fault of unusual character extends southeast from its point of origin east of Charleston Peak. The dip of the fault surface is steep throughout, but shifts from a northeast to southwest direction as the fault is followed toward the southeast. Deep dissection in this part of the range shows the fault relations exceptionally well. Thick Carboniferous strata with nearly horizontal attitude lie southwest of the fault and form a high scarp facing northeast. These

[15] This figure is derived by considering that the known part of the thrust plate has the form of a simple wedge; but, as the plate has great thickness at its present eastern front, the feather edge would be much farther east, and therefore the angle of the wedge must be considerably less than 6 degrees.

strata extend unbroken around the north end of the fracture. Northeast of the high scarp two thrust faults begin abruptly and extend northeastward. Clearly the steep fault was present at the time of thrusting and permitted the development of very different structure on the two sides. Other large faults trending northwestward in this range may have originated in the same way, although the latest movement on some of them has been vertical rather than horizontal.

Possibly another important fault or fault zone dating from the period of thrusting lies along Las Vegas Valley, effectively concealed by debris. The principal basis for this suggestion is in the radically different pattern of important thrusts on opposite sides of the valley. Although the broken condition of ranges to the north prevents complete study of the earlier structural features, it appears certain that some of the closely spaced thrusts in Spring Mountain do not continue across the valley. In this connection the change in trend of the thrusts on either side of the valley may be significant. The general strike of the larger thrusts is northerly, indicating that the regional thrusting force acted from west to east. Adjacent to Las Vegas Valley, however, the strikes have a strong easterly component. The two thrusts ending abruptly against the flaw southeast of Charleston Peak give a clear indication that the effective thrusting force in this part of the range acted from northwest to southeast. Such a deflection of the regional force may have been associated with differential horizontal movement along Las Vegas Valley.

Date of the thrust-faulting.—The stratigraphic record gives widely separated dates as the lower and upper limits for the thrusting movement. The Jurassic (?) sandstone is the youngest formation involved, so far as observation has shown, and the oldest sediments deposited after the movement are probably of upper Miocene age. According to this evidence, therefore, the deformation may have occurred either late in the Mesozoic or during the first half of the Tertiary. Two important epochs of orogeny in western United States came within these limits; the Sierra Nevada folding at or near the close of the Jurassic and the Rocky Mountain folding and thrusting during the early Tertiary. With positive evidence lacking, it is considered probable that the thrusts in southern Nevada were formed during one of these epochs. The subject has been discussed at some length elsewhere,[16] and only a brief statement will be given here.

[16] Geology of the Muddy Mountains, etc. Bulletin in course of publication by U. S. Geological Survey.

In earlier publications the Mesozoic date was favored;[17] but after further fieldwork and study it seems more probable that the thrusts are closely related to similar features in the northern Rockies. This relationship is suggested in the map (figure 1). A wide belt of flat thrusts, all with westward dip, is known in western Wyoming, southeastern Idaho, and northeastern Utah.[18] The Tertiary date of the thrusts in Wyoming and Idaho has been established, and there is strong inference that the Willard thrust is a contemporaneous feature. In some of the ranges of western Utah south of Great Salt Lake the structure is imperfectly known; but strong folding, on axes trending generally north-south, is reported from the Oquirrh,[19] Tintic,[20] and Canyon[21] ranges. For a large part of the region farther south it will be difficult to decipher the structure in the border region directly west of the plateau front, because a wide belt of Tertiary volcanics conceals most of the older rocks. However, the following points appear significant and are at least highly suggestive:

(1) The thrust-faults in the northern Rockies and in southern Nevada are similar in direction of strike and dip and in their general character.

(2) Between these two belts of thrusting the ranges, so far as they have been studied, show the effects of strong compressional deformation.

(3) From southern Nevada to northeastern Utah the eastern limit of intense normal faulting characteristic of the Great Basin parallels and coincides closely with the eastern limit of the earlier compressional deformation.

NORMAL FAULTS

General statement.—The complexity of fault problems in this region is suggested very inadequately by the network of fractures shown in figure 3. In some of the ranges the normal faults have been studied only incidentally, and further mapping will add many important faults to the chart. Only known faults of large throw have been included,

[17] C. R. Longwell: Am. Jour. Sci., vol. 51, 1921, p. 61; Jour. Geol., vol. 30, 1922, p. 63.

[18] G. R. Mansfield: Structure of the Rocky Mountains in Idaho and Montana. Bull. Geol. Soc. Amer., vol. 34, 1923, pp. 263-284.

Eliot Blackwelder: Wasatch Mountains revisited. Bull. Geol. Soc. Am., vol. 36, 1925, pp. 132-133.

[19] Economic geology of the Bingham mining district, Utah. U. S. Geol. Surv. Prof. Paper 38, 1905, pp. 56-57.

[20] Geology and ore deposits of the Tintic mining district, Utah. U. S. Geol. Surv. Prof. Paper 107, 1919, pp. 76-77.

[21] W. M. Davis: The Wasatch, Canyon, and House ranges, Utah. Harvard Bull. Mus. Comp. Zool., 1905, pp. 28-34.

G. F. Loughlin: A reconnaissance in the Canyon range, west-central Utah. U. S. Geol. Surv. Prof. Paper 90-F, 1914, pp. 57-58.

whereas a large number with small or moderate throw have been omitted. Without question some of the most important fractures are entirely concealed in the wide intermont valleys and can never be mapped satisfactorily. Moreover, there are difficulties of interpretation which can be overcome, if at all, only by detailed physiographic study; and such a study, to be of final value, should include a wider area than that considered here, as it must take account of recent changes in drainage which are of far-reaching significance. Any general discussion of the normal faults, therefore, necessarily recognizes numerous unknown or obscure relations, and only certain phases of the subject will be given brief consideration at present.

FIGURE 5.—*An old Fault in the southern Virgin Mountain Block*

The view, which is looking northeast along the old fault, was taken at point 2, figure 3. In the foreground and at the right are pre-Cambrian crystalline rocks; at left, sedimentary formations dipping eastward. The fault line is near the yuccas, with Kaibab limestone directly on the left, and it passes through the low saddle near the middle of the view, with white Tertiary limestone on the left. Throw of fault at least 12,000 feet. Grand Wash Cliffs show faintly in distant background.

Faults within the ranges.—Most of the faults represented by full line in figure 3 are ancient features which have only indirect expression, if any, in the present topography Such faults are either directly visible or are plainly indicated by stratigraphic evidence within the borders of the present ranges. Some have very large displacement and possibly mark the positions of former high mountain fronts. One of these old faults, whose strike is transverse to the present Virgin Range, is illustrated in figure 5. The entire stratigraphic section from Cambrian to Miocene (?) is thrown down against pre-Cambrian crystallines. At the

locality of the photograph the throw exceeds 12,000 feet, but all trace of the original scarp has disappeared. Faults of this character might be cited from practically every range in the area.

On the other hand, a few large faults within the ranges are marked by conspicuous scarps of remarkably fresh appearance, as in the example

FIGURE 6.—*Scarp of the White Basin Fault, in the Muddy Mountains, 900 feet high*

A bend in the fault conceals continuation at left. Rocks in scarp are Paleozoic limestones. Soft Tertiary beds on downthrow side, in wash. Fresh appearance of scarp due largely to recent uncovering. View from point 3, figure 3.

from the Muddy Mountains shown in figure 6. Two special factors enter into the interpretation of this scarp. Unusually soft basin deposits of Miocene (?) age lie on the hanging wall side, whereas hard Paleozoic limestones form the footwall. Therefore differential rock hardness is an important element in the problem. Moreover, the fault lies in a high structural basin which has been invaded by a tributary of Virgin River, and a stream course has developed directly on the line of the fault. In large part, therefore, the freshness of the scarp is due to recent exhumation rather than to recent movement. However, after making allowance for the special factors just mentioned, it is evident that this fault is considerably more recent than some others in the area. In the higher part of the range north of the locality of the photograph (figure 6) the scarp persists, although with reduced height, with rocks of equal hardness in hanging wall and footwall. On top of the block east of the scarp an old erosion surface has been tilted sharply eastward, apparently in connection with movement on the fault. This relation is especially significant by comparison with the Virgin Mountain locality (figure 5), where a flat erosion surface is developed across the fault itself.

Aside from the evidence cited above, indication that the normal faults belong to more than one period is seen in offsetting relations. Thus in certain ranges, particularly in the Las Vegas quadrangle, fractures with northwesterly trend consistently cut across all others. It is not certain, however, that this relation indicates very great difference in date, and clearly it is not safe to infer for the entire area that every fault with northwest strike belongs in the latest series. As noted in a preceding paragraph, in the eastern part of the Spring Mountain Range a group of northwesterly faults antedates the Keystone thrust, and this in turn is older than an important north-south fracture.

Many of the old normal faults have suffered a large amount of rotation since their inception (figure 7). This is especially true in the north half of the Las Vegas quadrangle, where faults with downthrow on the west are commonly very flat, in contrast to the steep attitude of those with downthrow on the east. In the Desert range one normal fault with stratigraphic throw of 9,000 feet has a present dip of only 15 degrees for a distance of at least 4 miles along the strike. Others in this same range have been rotated to a nearly horizontal position. These flattened faults have very sinuous outcrops, in response to topographic irregularities. By contrast, another large fault near the east side of the Desert range, with downthrow on the east, has been turned through the vertical and now has the appearance of a steep reverse fault. These relations indicate eastward rotation of the entire range, and this

interpretation is supported by the nearly uniform eastward dip of the strata, averaging 50 degrees, throughout the length of this range.

Border faults.—As stated in the preceding discussion, the faults exposed within the present ranges are, with a few conspicuous exceptions, very old. These faults may represent different episodes of orogeny, separated by time intervals of considerable length; but as all have been reduced to features of little importance in the present topography, they have been considered in one group. Probably these faults, and others of corresponding geologic age, also made a mosaic pattern in the bedrock between the present ranges, where they are now for the most part hidden beneath the deposits in the intermont valleys and on the fan slopes.

FIGURE 7.—*Normal Fault of large Throw*

The fault is on the west side of Pintwater Range, and it has a present westward dip of 20 degrees. Devonian dolomite above, Ordovician limestone below. Bedding above dips steeply to left, but is obscured by brecciation and secondary dolomitization. Ordovician beds are dragged almost parallel to fault, which probably had a much steeper dip originally and has been flattened by rotation.

The existence of important faults separating contiguous ranges is established by several lines of evidence. A fault-block relation is inferred, first of all, from the pronounced stratigraphic discordance commonly shown between adjacent ranges, each made of highly tilted but unfolded strata. In the typical case it is possible to explain this relationship by assuming a single profound fault along each interrange valley, on which there was normal movement accompanied by more or less rotation of the intervening crust blocks. Such an assumption might be made, for example, to explain the relations between the Sheep, Desert

Pintwater, and Spotted ranges, as all of these have a north-south trend, parallel to the prevailing strike of formations involved, and each range, on superficial examination, exhibits general uniformity and simplicity of structure. Other considerations, however, do not permit this ideally simple assumption. At various places on the fan slopes, or even in the middle of the wide interrange valleys, low ridges projecting above the waste repeat the stratigraphic and structural relations of the ranges, indicating clearly the presence of several important faults generally parallel. Moreover, the borders of some ranges are quite irregular, showing zigzag patterns, with angular embayments and promontories that suggest a number of intersecting faults rather than a single simple fracture. Finally, it is clear that some of the wide valleys are bounded on both sides by normal faults, and therefore represent either simple or complex graben. This combination of facts leads to the conclusion that the intermont valleys in general mark wide belts of profound faulting. There is direct evidence of several faults beneath the floor of Grand Wash Valley, the easternmost of these major features, although it is probable that a single predominant fault, following the base of the lower cliff, is responsible for most of the downthrow.

The evidence for important faults following the borders of various ranges is of several kinds. High, straight scarps, little dissected and with unusually small fan accumulations at the base, constitute the most important physiographic testimony. An especially conspicuous scarp of this character bounds the Arrow Canyon Range on the west, and others of more limited development are to be seen in certain parts of the Pintwater, Desert, and Sheep ranges. In the portion of the area characterized by interior drainage, playa flats commonly lie close to these scarps. Ranges in the area of exterior drainage are more favorably situated for direct study, as recent denudation has cleared away much of the bordering waste. Thus on both sides of the Virgin Valley the fault origin of high scarps is demonstrated by exposed portions of the actual fault surfaces and of the formations in the hanging wall. Even some of the ranges within the basin drainage show similar direct evidence locally, where stream courses crossing the mountain fronts have suffered recent incising. All of the border faults revealed in this way dip steeply away from the ranges, at angles of 50 degrees or more.

It might be supposed that these border faults are of essentially the same date as the eroded faults exposed within the ranges; that the present valley areas represent the blocks dropped lowest in a single general crustal disturbance, and that the scarps within the range blocks have been most effectively reduced merely because they stood at the

highest elevation. Two significant facts nullify such a supposition. In the first place, the border faults appear to be consistently steep, and they cut across faults which had been rotated greatly from their original attitude. In the second place, some of the old featureless faults appear in down-dropped blocks, considerably lower than neighboring border scarps. It appears, therefore, that the border faults are in general considerably later than most of the fractures exposed within the ranges. In other words, there have been at least two generations of fault-block mountains in this area. It is not necessary to assume that these two generations belonged to distinctly different epochs. Normal faulting may have been a continuing or recurring process covering a long period, but the earliest and latest effects of the process are in strikingly different stages of development.

It is certain, then, that every important existing range in the area owes to normal faulting much of its present elevation above the bedrock under the intermont valleys. In what degree is this faulting responsible also for the mountain elevations above the present surface waste in the valleys? Two extreme views of this matter will be considered. First, it may be assumed that the erosional debris derived from the upstanding masses during and since the latest block-faulting has sufficed merely to fill the interrange valleys to their present level. On this assumption the mountains of the area are true "basin ranges" passing through their normal cycle of erosion. Second, let it be supposed that after formation of the block mountains a long period elapsed, during which the mountain topography was practically obliterated by erosion of ranges and filling of interrange basins, and that the loose debris was then in large part removed, perhaps during the temporary regime of a more pluvial climate. On this assumption the present ranges are in large part resurrected and are to be considered as products of differential erosion, although they were typical basin ranges in the preceding cycle.

The conditions of the last assumption have been at least partly realized in the Virgin and Muddy ranges. Grand Wash and Virgin River have removed Quaternary and Pliocene (?) deposits from their wide valleys to a depth of several hundred feet. Accordingly, the bordering scarps, preserved on resistant limestones, appear high and fresh. Restoration of the transported material would greatly reduce the effective height of the two ranges and would give them a more subdued appearance. The scarps would not be entirely hidden, but they would no longer give an impression of recency. On the other hand, if the exterior drainage system were suddenly removed from the valleys in their present state, allowing a return of basin conditions, then the

FIGURE 1.—VIEW LOOKING WEST FROM WESTERN SLOPE OF DESERT RANGE

The view is taken from point 4, figure 3. Pintwater Range in background. Remnants of erosion surface in foreground and on low ridge in middle ground. Rocks under the nearer remnant dip 50 degrees toward observer. This remnant is 600 feet above valley on right and 1,500 feet above north-south valley between the ranges.

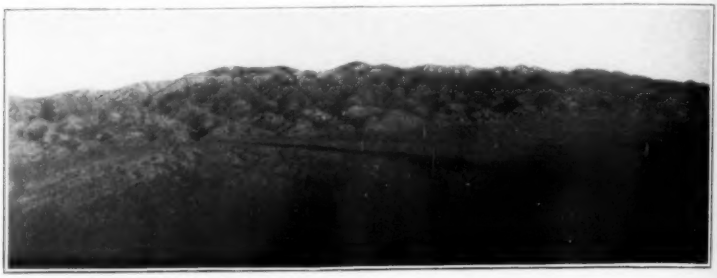

FIGURE 2.—WEST SIDE OF SHEEP RANGE

The view was taken from east slope of Desert Range, from point 5, figure 3. Top of Sheep Range is 12 miles distant and more than 5,000 feet above valley. Flattish surface near top may represent prefaulting surface. Note straight base of range and dissected bench above the base. This bench is a mile wide and there is a fault near its inner margin. Scarp above is badly dissected. Note dissection of the fan slope and shifting of fan material to lower level.

FIGURE 3.—LOOKING SOUTHWEST TOWARD SPRING MOUNTAIN FROM SOUTHERN END OF PINTWATER RANGE

The view was taken at point 6, figure 3. Top of Spring Mountain is 20 miles distant. Valley in front of observer is 3,000 feet in elevation; crest of Spring Mountain, above 10,000 feet. An important northwesterly fault at base of high range. Note the even slope of waste from position of fault to the intermont valley, broken only by isolated foothill blocks. Note also the even crest of the range.

VIEWS AMONG THE RANGES IN THE LAS VEGAS QUADRANGLE

exhumed scarps, as we now see them, would endure for considerable time, giving a false implication of very late faulting.

Let us turn to the ranges in the Las Vegas quadrangle. Las Vegas Valley, from a point 25 miles northwest of Las Vegas, drains into Colorado River. Farther north and west the valleys contain a series of interior basins, separated for the most part by low divides of fan material. With a moderate increase in rainfall this entire area would now become part of the Colorado River drainage, and possibly during the late Pleistocene a vigorous exterior drainage actually existed in these valleys, removing a large part of the basin waste. It is very apparent that the level of debris was once much higher than at present, for many remnants of an old surface, standing 600 to 1,200 feet above the bordering valleys, are conspicuous about the Sheep, Desert, Pintwater, and Spotted ranges (plate 19, figures 1 and 2). These remnants are cut across the tilted formations of hard rock, and many of them retain a veneer of old rock waste. It is obvious that the low Desert Range was at one time largely buried and stream channels crossed it from the west slope of the Sheep Range.

The theory of a former exterior drainage is attractive, but several considerations are against it. As a first test we may compare the topographic features about Las Vegas Valley with the west slope of Spring Mountain. This slope is separated by the high range from the Colorado River basin, and without reasonable doubt it has belonged to the interior drainage system for a very long time. In stage of physiographic development, however, the two sides of Spring Mountain are strikingly similar. Each side has a long slope of waste, reaching from the high central mountain ridge through the foothills to the intermont valley (plate 19, figure 3). On each flank are incised channels about 150 feet deep in the waste near the top of the slope, gradually decreasing in depth and disappearing at lower levels. Rock-cut benches similar to those about the Desert range are also conspicuous along the northwest flank of Spring Mountain. Obviously the opposite sides of the range have had a similar physiographic history, and the safest conclusion appears to be that this history is connected with the development of desert basins. In such development a lowering of intermont waste might be accomplished through one of two processes: through capture of one basin by another at considerably lower elevation or through down-faulting in part of a single basin. These two processes might well cooperate, as in a series of neighboring basins the second process would logically involve the first.

It will be assumed, then, that renewed faulting has occurred along some of the range borders in the Las Vegas quadrangle within late

geologic time. This theory is strongly supported by the data now in hand. Along several steep scarps, particularly in the Pintwater and Desert ranges, fans are in the incipient stage, and the coarse material forms a thin veneer over playa silt, which until a very recent date reached almost to the very base of the scarps. The suggestion of recent faulting at these localities is obvious. More convincing evidence is furnished by the Desert and Sheep ranges near the north end of the quadrangle. An old valley, sloping to the west, has great width in the middle of the Desert Range, and evidently had its original head considerably east of the present eastern border of this range.

On the west slope of the range this valley is becoming incised, perhaps due to subsidence of the intermont valley on the west. On the east the valley has been beheaded and is being rapidly destroyed by a steep canyon tributary to the playa on the west side of the Sheep Range (plate 20, B and C). This playa occupies a low basin, which is completely isolated by ranges and high divides. Washes leading into it have abnormally steep gradients. The area of the basin is small, as its northern boundary is only a short distance beyond the limit of the quadrangle, and the playa floor lies 1,500 feet below the beheaded valley in the Desert Range. These relations comprise weighty evidence that important subsidence occurred in this basin, probably along the fault bordering the Sheep Range, in very late geologic time.

It is believed, therefore, that relief in this area has been produced and maintained chiefly by faulting. All of the ranges have been greatly modified by erosion, and there are no scarps comparable in height or freshness to those of the Sierra Nevada, Inyo, and Wasatch ranges. Apparently other parts of the Basin Range province have been more active than this during the latest geologic epoch.

Dates of normal faulting.—So far as observation has shown, the fan slopes in this area have not been disturbed by faulting, and therefore there is no basis for considering any of the faults active at present. Probably the latest important movements occurred in Pleistocene rather than Recent time. The ranges were blocked out in essentially their present positions not later than the Pliocene, as thick basin deposits believed to belong to that epoch accumulated in the existing intermont valleys. The amount of post-Pliocene faulting has not been estimated. Probably a large amount of subsidence in the basins occurred during Pliocene deposition, for, although these sediments generally show increased coarseness near the mountain borders, there is nothing in their texture to indicate proximity to a high scarp.

A number of important faults older than the probable Pliocene sedi-

A.—Part of old wide Valley showing its width

View from a point near east side of range at 7, figure 3, looking southwest. Valley slopes to right, toward west side of range.

B.—Looking North from same Viewpoint as in A, showing present eastern Limit of old Valley

Note dissected edge of valley fill and sharp descent into canyon which has beheaded the valley.

C.—Looking Northeast from same Viewpoint as in A and B, across eastern Border of Desert Range into Sheep Playa

North end of Sheep Range in distant background. Surface of Sheep playa is 1,500 feet below observer.

VIEWS FURNISHING EVIDENCE OF RECENT FAULTING

ments cut the Miocene (?) formations and others were formed during or before Miocene deposition. Many of the ancient faults cutting Mesozoic and Paleozoic strata are not situated favorably for dating with respect to the Tertiary deposits. Probably some of these faults were initiated during or soon after the development of the great thrusts.

Conclusion

Future publications will contain detailed geologic maps of the Saint Thomas and Las Vegas quadrangles and will present a more complete account of the geological features in these areas. The aim of the present paper has been to call attention to the more prominent structural features and to suggest their significance. It is apparent that the thrust-faulting was regional in character, and we should expect to discover its effects in other ranges to the north and possibly west of these quadrangles. The history of normal faulting has been long and complex. A regional physiographic study should provide a useful key to the later stages of this history. Extension of the structural studies beyond the area considered in the present discussion may give additional light on other problems, and particularly on the date of the thrusting movement.

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ORIGIN OF CALIFORNIA PETROLEUM[1]

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INTRODUCTORY

Chemical and other scientific study of petroleum has lagged far behind oil-field developments in California, as it has in other regions of the world. The fact is doubtless due to the ease with which new production

[1] Manuscript received by the Secretary of the Society September 20, 1926.

has been obtained in the past in this State. At all events, commercial enterprise in this industry has usually regarded questions as to origin, chemical character, and ultimate utility of oil as having at best only an academic interest. But, with the rapidly growing demand for petroleum and with the coincident depletion of known sources, questions regarding origin, etcetera, and the possibility of scientific aid in further exploration will become unavoidable, and any information likely to throw light upon possible hidden reserves will be welcome, and research may meet with better support.

A complete review of the scientific work done in California might aid in the further study of its oils, but it would lead beyond the limits set for the present paper. We may, however, recall here the belief, now rapidly growing among geologists as well as chemists, briefly stated by F. W. Clarke as follows:[2]

"Wherever sediments are laid down, inclosing either animal or vegetable matter, there bitumens may be produced. . . . Seaweeds, mollusks, crustaceans, fishes, and even microscopic organisms of many kinds may contribute material for the change." . . .

Chemical study can not alone afford complete information as to the origin of bitumens without a similar study of the nature and origin of the rocks inclosing them, including both their organic and inorganic contents.

California oils do not all come from a single series of sediments. They have been found in all the more important series of strata in this State, from Lower Cretaceous to Pliocene or later, each in some locality having furnished its own type of oil. Some deposits are, of course, secondary.

Probably more than 95 per cent of the State's oil production has come from Tertiary strata, and of this part probably as much as 85 per cent has been derived from Miocene formations; so that the strata of this period may be regarded as being the chief source and as containing the source materials of the major part of California petroleum. Regarding the source materials, it would seem that the nature of the organisms that dominate the Miocene, if there are such, should determine the character of the oil dominant in California production, or *vice versa*, and no doubt this is the case. If other formations older or younger than the Miocene have been the source of oil, we may expect the character of the oil to vary in accordance with the class of organic materials found therein. Doubtless, too, the character of the oil would

[2] Clarke: (1924.) Data of geochemistry. Bull. No. 770, U. S. Geol. Surv., p. 754.

be affected to some extent by the nature of the inorganic materials with which it was associated, both in its origin and in course of its progress toward its pools of accumulation or storage. Other authors have reached these general conclusions before.

The Bituminous Shales

General statement

Most of the source rocks of California petroleum are included in the "bituminous shales" of the Miocene series, although strictly they are rarely shales in the usual sense of being argillaceous. For the most part they are highly siliceous or contain, besides, sandy or calcareous material or strata composed of such. However, the white, siliceous, sometimes chalky, but more often hard, shaly rocks, such as are characteristic of the California Miocene, and especially of the Monterey group, seem not to be confined to any single series. In some localities chalky diatomaceous shales extend up even into the Pliocene and into other formations unconformably related to the Monterey group, which is itself especially characterized by diatomaceous beds.

On the other hand, rocks very similar in lithologic appearance have been classed as Oligocene on alleged fossil evidence; also, certain lithologic members of the Eocene have much resemblance to these Monterey shales, and Diatomaceæ are abundant in beds that have been regarded as Upper Cretaceous in age. Neither the presence of diatoms nor of white siliceous shales is a safe guide for age determination of strata. The rocks should be studied faunally, microscopically, and in some cases chemically, and otherwise. There are, moreover, in the California Tertiary several varieties of siliceous as well as bituminous shales, the origin of which has been diverse, not only with regard to their organic, but also with regard to their inorganic contents, all of which may vary locally. In Blake's original description of the "Monterey formation" he gives details[3] of about 81 feet which, he says, form the upper part of the strata. The largest unit of the beds described by him he denotes as "white siliceous earth, light and charged with infusoria," 50 feet in thickness.

One infers from reading his account that the entire group of strata at Monterey is formed of siliceous organic materials abounding in the remains of marine plants and animals, of which he mentions only two classes, "infusoria" and Foraminifera. He does not directly mention

[3] W. P. Blake: (1854-1855.) Proc. Phila. Acad. Sci., vol. vii, pp. 328-331.

Diatomaceæ, although it can not be doubted that by infusoria he meant only diatoms, following the custom of microscopists of his day.

He also referred to the bituminous character of these rocks, which upon heating "give off an empyreumatic odor." He did not attempt to connect the bitumen with the organic contents of the rock. He stated that the formation extended south to and beyond the Mission of San Carlos, but in fact it extends much farther.

Dr. A. C. Lawson, in his discussion of the geology of Carmelo Bay,[4] gives a more complete account of the rocks which he includes in the "Monterey series," which he says is "certainly over 1,000 feet in thickness and richly fossiliferous." His lithologic study of these beds is far more detailed and extensive than Blake's, and in summary he says:

"The infusorial beds at Monterey appear, therefore, to be exceptional and not representative of the series as a whole. Moreover, it becomes probable from a microscopic examination that the mass of the white chalky shale, in part at least, is the fine ash of a very acid volcanic eruption." . . .

And later, in continuation of the subject, he says:

"The suggestion of the volcanic origin of the whole of the Monterey series yielded by the microscope is strengthened by a chemical analysis of a representative specimen of the chalky rock." . . .

The view expressed by Lawson seems to have only a local application, but the fact remains that acid volcanic ash, tuffs, and other ejectamenta are common in the lower Miocene of the California Coast ranges.

Blake himself, in describing the Lower Miocene rocks of Poso Creek, Kern County, says:[5]

"The principal point where Tertiary strata are developed and characterized by fossils is at Pose Creek, near the Tejon Pass. They consist chiefly of volcanic sands and pumice-stone, with argillaceous sandy beds." . . .

H. W. Fairbanks, who had studied the "bituminous shales" of the Monterey Group[6] microscopically, chemically, and otherwise, especially as they occur in western Santa Barbara County, after reviewing briefly the statements made by Lawson, mentions specifically the colloidal or opaline character of the silica, and continues thus:

"The fact that in different specimens, and sometimes in the same one, all stages of obliteration can be noted, from those (organisms) in which the structure is discernible to those which appear as faint dots, gives support to the view that the silica was derived chiefly from disintegrated organic remains." . . .

[4] Lawson: (1893.) Bull. Dept. Geol. Univ. Calif., vol. 1, pp. 22-23.
[5] Blake: (1855.) Proc. Am. Assoc. Adv. Sci., vol. 9, p. 224.
[6] Fairbanks: (1896.) Bull. Dept. Geol. Univ. Calif., vol. 2, p. 13.

As to the class of organisms from which the silica of the shales was derived, Fairbanks gives no clear account, nor does he mention Diatomaceæ, sponges, Radiolaria, or other classes. He admits that volcanic ash beds are found in the Lower Miocene, even at Point Sal, the geology of which he was describing, though far below the horizon of the bituminous shales. Similar beds of rhyolite ash and tuffs are known in the Lower Miocene strata south of San Luis Obispo, east of Los Olivos, western Los Angeles County, and many other places along the coast of California.

The siliceous shales just described especially characterize the Miocene north of Point Conception, but they occur also to a less extent south of it. In Kern County, as also in San Luis Obispo and Monterey counties, these shales often compose vast aggregates of strata 5,000 to 6,000 feet in thickness, including a few scattered beds of other character, sandstones or limestones.

The Santa Ynez range, extending east to west through southern Santa Barbara County, divides the California coast into two distinct provinces of Tertiary deposits, with reference to both their lithology and their organic contents, as well as to the character of oil produced, to a great extent.

NORTHERN PROVINCE

In the northern province, including the counties of Santa Barbara, San Luis Obispo, Monterey, Kern, and Fresno, the Tertiary deposits are for the most part dominated by marine Miocene strata, of which the most conspicuous part is the Monterey group, characteristically composed of white, diatomaceous shales, in which locally there is a large percentage of white rhyolitic ash. The "bituminous shales" of the northern province are almost exclusively Miocene in age, though narrow zones of supposed Oligocene, and of Eocene outcrop in certain districts, underlying the Miocene and later deposits.

This northern Tertiary province is occupied by two basins of deposition, with certain differences, more apparent in the older and younger strata, but not so pronounced in the Miocene, which has strong resemblance throughout the entire province.

The southern, or Santa Maria, basin covers western Santa Barbara and a part of San Luis Obispo counties, while the northern, to which the name "Temblor" has been applied, includes the Salinas and San Joaquin valleys. Eocene and possibly Oligocene beds occur locally in the Temblor basin, namely, along the northeast flank of the Mount Diablo range, where they are only of minor interest to the oil geologist. In the Santa Maria basin Eocene and Oligocene strata are known along

the eastern and southernmost borders, namely, in the San Rafel and Santa Ynez ranges, but unlike those of the northern basin. The difference is both lithological and faunal. No oil has been reported from the Eocene of the Santa Maria basin, while it is well known in the northern basin.

It is in the Pliocene deposits that the two basins of the northern province show the greatest difference. Those of the Temblor basin are almost wholly of fresh-water origin and terrigenous, rarely containing diatoms. In the Santa Maria basin no such fresh-water deposits are known in the Pliocene, the beds being marine and often highly diatomaceous. The much-discussed diatomaceous strata of the California oil fields dominate the Miocene of both the Temblor and Santa Maria basins in the northern province of the California Tertiary, and characterize it there.

SOUTHERN PROVINCE

In the province of the Tertiary lying south of the Santa Ynez range both the Eocene and the so-called Oligocene series have wide distribution, covering a large area north of the Santa Clara Valley, thus forming a large part of northern Ventura County, and they also extend into more southerly districts, as in the Santa Susana, Santa Monica, and Puente ranges. Limestones and foraminiferal shales are common in these Lower Tertiary beds, especially in the Eocene of the districts north of the Santa Clara Valley, as has been shown by various writers.

While Miocene strata occur abundantly in the southern province, they lack the prevailing siliceous aspect and diatomaceous character of the Miocene in the region to the north On the contrary, they are often sandy, and where siliceous beds occur they contain layers and lenses of limestone and many strata abound in Foraminifera and other marine animal forms. The Miocene beds of the south not only do not contain thick aggregates of diatomaceous shale, such as those of the north, but in many districts such beds are rare in the Miocene, or, if present, are obscured by other materials.

The Pliocene deposits of the south are conspicuously sandy and rarely contain important diatomaceous beds, although they are wholly marine. The micro-organisms dominant in the Lower Tertiary, including the Miocene of the southern province, are Foraminifera, and therefore are animal rather than plant forms.

While no special field study of the formations south of the Santa Ynez range has been made for the purpose of determining the source of their petroleum, yet various authors have noted the abundance of foraminiferal remains among their organic contents. Limestones and

concretionary layers in which calcareous matter abounds are frequently mentioned by geologists who have worked here. The age and circumstances of the Lower Tertiary beds are probably against the preservation of recognizable forms in many cases, though the limestones may usually be regarded as being of animal—that is, foraminiferal—origin. Partial metamorphism has affected the Lower Tertiary beds here to a considerable extent in many places.

W. L. Watts states concerning the Eocene formations of the Sespe district[7] that

"The rocks comprising this horizon consist of hard sandstones, a little conglomerate, and dark-colored shale. Most of these distinctly Eocene formations, which the writer has observed in Ventura County, show more or less evidence of metamorphism." . . .

W. S. Kew, who has given more of the geologic details of this region, in describing the several groups of the Eocene, merely mentions "organic strata," without any more definite statement as to the nature of their organisms. With reference to the Tejon group of Ventura and Los Angeles counties and its relation to petroleum, he says:[8]

"The Tejon rocks in this region are composed partly of shale and partly of sandstone, all of which are well indurated, the sandstone in places resembling quartzite. Below the white sandstone at the top of the Tejon occur shaly beds that may be composed in part of organic material, such as diatoms and foraminifers, in sufficient quantity to have formed oil." . . .

References to such statements might be extended indefinitely, nearly all writers noting the foraminiferal and other marine animal forms in the older Tertiary beds. In these respects, as well as in the induration of the beds, they differ from their equivalents of the northern province.

Watts believed the Oligocene beds of Ventura County to contain primary deposits of oil, and gives the following comment:[9]

"The evidence thus far gathered concerning the petroleum-yielding rocks of California leads to the following conclusions: First, that the Oligocene formations, previously referred to, contain a primary deposit of petroleum; that this deposit is found in the lower portion of a certain bed of dark-colored shales, and in certain strata of sandstone, interstratifying and immediately underlying the said shales; that the Eocene formations also contain primary deposits of petroleum." . . .

There are many places in the southern province, especially in Ventura County, where the Miocene beds are well stocked with Foraminifera, as

[7] Watts: (1897.) Bull. No. 11, Calif. State Min. Bur., p. 58.
[8] Kew: (1924.) Bull. No. 753, U. S. Geol. Surv., pp. 29-30.
[9] Watts: (1897.) Bull. No. 11, Calif. State Min. Bur., p. 59.

at Carpenteria, about Sulphur Mountain, and farther south. In the former locality the bituminous shales are completely filled with Foraminifera of many species, and also well saturated with bitumen, the tarry oil issuing from the edges of the strata in considerable quantity. This horizon is perhaps the source of the oil occurring at Summerland, although proof of this is lacking.

On the south flank of Sulphur Mountain shales of similar character, filled with the well-preserved remains of Foraminifera, are abundant in the vicinity of the old tunnels driven here for oil in the early days.

The oil produced from many of the wells of this district belong to the Ventura type, and it is not improbable that it originated in the Foraminifera-bearing shales of the kind exposed here.

In Los Angeles County the Lower Puente Shale, according to Arnold,[10] embraces:

"At least 2,000 feet of shale, in the main earthy, but with minor members of siliceous nature, the whole gray or brown from the presence of iron and bitumen. Thin, fine-grained sandstones are interbedded with the shale from top to bottom, and lenticles of gray limestone weathering yellow also occur. . . .

"The only evidence of life thus far discovered consists of Foraminifera and diatoms, so common in the Miocene of the Pacific coast. These occur in both shale and limestone." . . .

Watts apparently suspected, as others have done since, a multiple source for California petroleum, as alternatives applicable to different localities, and states a view not altogether new, as follows:[11]

"Bearing in mind the immense amount of seaweed which has in all ages flourished in the ocean, it is impossible not to recognize this material as a probable source from which petroleum may have been formed. This view is strengthened by the fact that water accompanying petroleum in the Central Valley of California is rich in iodine." . . .

This statement regarding the association of iodine with the oil-field wafers of the San Joaquin Valley has often been noticed by other writers. His suggestion that the larger marine plants may have been a source of petroleum recalls the view first expressed by J. S. Newberry in 1859,[12] though not for California petroleum. The theory was further elaborated by Lesquereux,[13] and later by Newberry himself.[14] Concerning the abundance of marine plants to this end, he says:

[10] Arnold: (1907.) Bull. 309, U. S. Geol. Surv., pp. 103-104.
[11] Watts: (1900.) Bull. No. 11, Calif. State Min. Bur., p. 202.
[12] Newberry: (1859.) Ohio Agri. Rept. Rock Oils of Ohio, pp. 2-5.
[13] Lesquereux: (1866.) Bull. Soc. Nat. Hist. Neuchâtel, vol. 7, p. 235.
[14] Newberry: (1873.) Geol. Surv. Ohio, vol. i, p. 156.

"It is true, however, that a great growth of aquatic vegetation sometimes takes place remote from land, where the plants have no attachment to the sea-bottom. Of these areas we have a type in the "Sargasso Sea," . . . Under all such sheets of vegetation, in a sea where fine mechanical sediments are being deposited, we must necessarily have an accumulation of mud containing a large percentage of carbonaceous matter; in other words, the elements of a bituminous shale." . . .

In none of these discussions was reference made to the so-called calcareous Algæ, such as occur in some of the Eocene districts of the California coast, though it is possible that they should have been included among the probable sources of petroleum. Other forms of seaweeds have not been shown to occur in quantity in any of the Tertiary deposits of California, though their remains are not unknown.

From the foregoing statements we may conclude, as most geologists have done, that most of the oil of the northern province of the California coast has had its origin in the siliceous shales of the Miocene, from some association with which it chiefly comes. The dominant organic content of these shales is in fact almost wholly Diatomaceæ, and these organisms often occur in immense volume, sometimes to the extent of forming strata many hundreds of feet in thickness. They constitute the only class of oragnism that do occur in sufficient quantity to form a source commensurate with the oil supply.

EARLY DEVELOPMENTS

The earliest commercial production of the State began in the southern province in the late 60's and early 70's, in the fields of southern Ventura and northern Los Angeles counties. These counties make up the larger part of the southern province, though oil of early type is no longer dominant here. The early product was an oil which at first was reported as containing paraffins, and while asphaltic oils were well known here, they were not in demand and at first not much produced. On the other hand, the so-called paraffin oil was in considerable demand, chiefly for refining, and this led to the early development of a relatively large production. It was later proved by Peckham and Mabery that these oils carry no paraffins, but are characterized by a large percentage of allied compounds—olefins and naphthenes—forming several series of unsaturated hydrocarbons. They are not primarily derived from Miocene strata, but from older Tertiary beds, Eocene and Oligocene, as said before.

In the north the production of oil in commercial quantity began with the discovery of the Kern River field in 1899. Soon after followed the discovery of the McKittrick, Sunset (Maricopa), Midway, and Coa-

linga fields, and their asphaltic oils rapidly became the dominant type of California production. More recently the south has contributed enormously to this type of oil, especially the Los Angeles basin.

Classes of Oil Known

General statement

As no final scheme for the classification of petroleums has yet been provided by chemists, none will be proposed here. We may refer, however, to the discussions of this subject by Mabery,[15] Clarke,[16] and others. In a rough classification of bitumens suggested by Peckham,[17] he says in part:

"I am convinced that all bitumens have, in their present condition, originally been derived from animal and vegetable remains, but that the manner of their derivation has not been uniform." . . .

In this paper he recognizes "four kinds of bitumens," thus:

"1. Those bitumens that form asphaltum and do not contain paraffin.
"2. Those bitumens that do not form asphatum and contain paraffin.
"3. Those bitumens that form asphaltum and contain paraffin.
"4. Solid bitumens that were originally solid when cold or at ordinary temperatures."

With reference to California productions, it will soon be apparent that this classification can only be adopted in a modified form, as Peckham himself has shown in quotations which follow.

Oils of the Ventura type[18]

Early in the development of the industry in California, oil of paraffin base had been reported from the Newhall field, as recorded by Joseph D. Weeks, apparently from preliminary analysis. Calling attention to this and without referring to his earlier statement, Peckham says:[19]

"Soon after I reached California, in 1893, Dr. Salathé showed me what he claimed was crude paraffin from one of the wells in the Torry Canyon. He dissolved some of the material in naphtha, filtered the solution, and evaporating the naphtha, obtained a waxlike solid. He claimed that this experiment proved the existence of paraffin in the Torry Canyon crude oil. I afterwards visited the Torry Canyon and was given a mass of dark-brown, waxlike substance, which I was told was the other half of the mass given Dr. Salathé, and that the whole was taken from the sucker rods of one of the wells. I

[15] Mabery et al.: (1905.) Am. Chem. Jour., vol. 33, pp. 251-292.
[16] Clarke: (1920-1924.) Data of Geochem., U. S. Geol. Surv.
[17] Peckham: (1880.) Xth Census Rept., pp. 67-69.
[18] "Venturaite" of Peckham.
[19] Peckham: (1897.) Jour. Frankl. Inst., December 21.

have since examined this material sufficiently to prove that it does not consist of any form of paraffin, but is an unsaturated hydrocarbon, readily combining with sulphuric and nitric acids. It is no doubt a solid olefin or naphthene."

This determination was afterwards confirmed by Mabery,[20] not only for the Torry Canyon crude oil, but for that of other localities as well. He says in part regarding these:

"So far as we have carried the examination of California petroleum no solid paraffin hydrocarbons have been found. From several fields oil has been obtained, whose higher distillates, on standing, deposited large, well-defined crystals, but unlike paraffin." . . .

Oil containing similar hydrocarbons was earlier found at Summerland by Mabery,[21] who seemed to regard it with some surprise. It is not very difficult, however, to show geologic relationship between Summerland and the fields along the south border of the Santa Clara Valley. It is likely, moreover, that similar oils exist throughout intervening areas, and that they may be traced to a single horizon of origin.

It has recently been shown by W. S. Kew[22] that the Torry Canyon oil probably comes from strata of Upper Eocene age, and in rocks of this horizon we may expect to find similar oil in other districts of California, if they are petroliferous at all. Similar oils have been produced from the Puente Hills, in eastern Los Angeles County, and other southern districts. Mabery, who has studied numerous examples of oil from this part of the State, which at the time of his report formed almost the entire production, says in summary:[23]

"California petroleum differs totally from the Eastern oils—Pennsylvania, Ohio, Canadian, etc.—and also materially from Russian oil, in not containing members of the series C_nH_{2n+2}." . . .

These olefine (or napthene)-bearing oils of Ventura and Los Angeles counties, although the first to be produced in quantity in California, now form only a minor part of the State's production, not unimportant, however, since they are still in demand for refining purposes.

ASPHALTIC OILS

In 1892 successful wells were drilled in the Los Angeles City field, and a different type of oil produced, for which there seemed at first to be little, if any, use. In 1899-1900 the Kern River, McKittrick, Sunset, and Midway fields were discovered by drilling, and soon after

[20] Mabery: (1906.) Jour. Am. Chem. Soc., vol. 28, p. 424.
[21] Mabery: (1905.) Am. Chem. Jour., vol. 33, p. 275.
[22] Kew: (1924.) Bull. 753, U. S. Geol. Surv., pp. 109, 162, 163, etc.
[23] Mabery: (1900-1901.) Proc. Am. Acad. Arts and Sci., vol. 36, pp. 255-304.

the heavier oil from the Coalinga field was added to this class of production. These oils now constitute the type characteristic of California, which gained its dominance after 1900. It carries large amounts of asphaltum and little, if any, paraffin or similar hydrocarbons, although in some cases they have been reported. The oils of Kern County often carry as much as 40 or 50 per cent of asphaltum, and much of it has been refined primarily for the asphaltum it contains, the other products being subordinate. This was the first use made of the heavier oil from the Sunset field, as it was also of some of the oil from the Kern River field and also the McKittrick field.

More recently, chiefly since 1916, oils of this class have been produced in large quantities in southern California, namely, in the Los Angeles basin, though it began here with the early drilling of 1892. This type of oil is derived chiefly, or almost wholly, from Miocene strata, just as that of the Ventura type is derived from the Eocene. It has been obtained from all horizons of the Miocene, from almost the oldest to the youngest, and is preeminently characteristic of this period in California. Indeed, the Miocene rocks have produced no other class of oil, although the percentage of asphaltum varies greatly. Analyses of these oils are many and well known and hardly need comment. Reference may be made, however, to the fractional analyses contained in Bulletin 63 of the California State Mining Bureau and to the more detailed analyses published by the U. S. Bureau of Mines (see Bulletin 19, etcetera).

MIXED OILS

In some districts of California oils have been produced which contain both asphaltum and the unsaturated hydrocarbons, olefines or naphthenes. Such have been reported from Ventura County and are believed to occur in the Maricopa and Coalinga districts. North of Santa Paula, Ventura County, asphaltic deposits are abundant, though analyses show that some of the oil produced here, as in Wheeler Canyon, contains olefines and naphthenes. There is reason to believe that similar oils have been found in other parts of the State, as in the Puente Hills and Kings and Fresno counties.

It would thus appear that, with some modification, Peckham's first three classes of oils have been found in California, and in fact form important parts of the State's production. Substitution must be made, however, of the Ventura type of oil for the second class proposed by him. If it appears that these must be regarded as distinct from oils containing the true paraffins, then his classification will not apply here.

PARAFFIN OILS

Oils containing true paraffins have been reported from different parts of the State, though, as far as known, not in large quantity. Allen and Jacobs[24] found paraffin wax in oil from some of the wells in the eastern part of the Coalinga field, namely, from wells of the "W. K." and Coalinga-Mohawk companies and neighboring properties.

Some of the wells on the north border of section 28, township 19-15, obtained in 1911 an oil from one horizon which, according to the published analysis,[25] contained a large amount of "paraffin wax." Wells a few miles south of Coalinga obtained about the same time an oil of similar appearance, also said to contain paraffin, though no exact information is available. In both cases the oil appears to have come from Eocene strata buried under later formations. Similar oil is also found in wells drilled on sections 25 and 26, township 25-18, Devils Den district, though no large production has been obtained. Other instances of such oils have been reported, but, as far as known, all are derived from rocks of the older Tertiary.

BENZOL-BEARING OILS

The first oil discovered by drilling in the Coalinga field was one of unique character, not belonging to any of the preceding classes. It was found by drilling in the old "Oil City" field in 1893, though production did not begin until 1896. This oil is of light gravity, 40 degrees to 42 degrees, Baumé, and contains aromatic compounds, naphthenes, etcetera, and is said also to contain both asphaltum and paraffin,[26] though this statement is not confirmed by Mabery's analysis.[27] Among the distinctive features of this oil is its content of benzol, toluol, xylol, and other such derivatives, not often found in California oils.

This oil is usually kept isolated from other oils by the purchasers, and in refining furnishes its own class of products, including toluene. In quantity it forms only a small percentage of the production from the Coalinga field, and its importance comes chiefly from its unusual character. This oil is derived from the so-called "Moreno formation," which has been referred to the Upper Cretaceous, Chico, or later beds. Along their strike these beds extend far to the northwest and oil has been found in them at a few other points, as in the Vallecitos. As to their age, there is some difference of opinion; they were first described by the writer in

[24] Allen and Jacobs: (1911.) Bull. 19, U. S. Bur. Min., pp. 9-12.
[25] Anderson and Pack: (1915.) Bull. 603, U. S. Geol. Surv., p. 142.
[26] Anderson and Pack: (1915.) Bull. 603, U. S. Geol. Surv., p. 140.
[27] Mabery and Hodson: (1900-1901.) Proc. Am. Acad. Arts. and Sci., vol. 36, pp. 255-304.

1905[28] as being of Eocene age, and in view of a well-developed fauna, which is clearly Eocene, and a lithology, which is also typically Tertiary, and not Cretaceous, they must still be regarded as being in large part Eocene, though the boundary is not well defined.

OTHER TYPES OF OIL

Other classes of oil in smaller quantities have been reported from different parts of the State, some Tertiary and some older. Water-white oil has been obtained from wells drilled into crystalline rocks on the south flank of the Placerita Canyon, not far from Newhall. Its real source is probably in the Tertiary shales that overlie the crystalline rocks on the north.

Light oil has been reported in connection with the quicksilver deposits of Lake and Napa counties and has been observed by the writer south of Coalinga, in similar occurrence. Its source has probably been in the Lower Cretaceous beds involved with these deposits.

It is very probable that other undescribed types could be found in some of the many districts that contribute to the aggregate production of California. In some cases more than one type of oil has been yielded by a single well, each coming from distinct oil-bearing beds penetrated by the boring. This has happened in the Coalinga field and in western Kern County, but the topic, while interesting, need not be followed to any greater extent at this time.

Initial Sources of Petroleum

Considering the foregoing facts, it would appear that, disregarding for the moment the exceptional types of oil and the third class, consisting of mixtures, or blends, the major part of the production of California is reduced to two classes: first, that of the Ventura type, for which the name "Venturaite" was proposed. It formed the bulk of the State's production prior to 1895. It came chiefly from Ventura and the northern and eastern parts of Los Angeles counties, though no longer dominant there. Second, as regards historic development, came the asphaltic oils, of the type produced in the counties north of Ventura and more recently in the Los Angeles basin, as at Huntington Beach, Santa Fe Springs, Signal Hill, etcetera. This type has formed the bulk of the State's production since 1900. Peckham's third class has already been mentioned as possibly consisting of mixtures of the two preceding types, the explanation of which is simple.

[28] F. M. Anderson: (1905.) Proc. Calif. Acad. Sci., 3d ser., vol. 2, pp. 162-168.

From the facts observable in the field, it may be concluded that the two major types of oil have had distinctive organic sources as well as distinct formations of origin; that the asphaltic oils, chiefly derived from the Miocene, had their origin in the vegetable organisms, Diatomaceæ, etcetera, such as characterize this series, especially the Monterey group; that the oils of the Ventura type, containing naphthenes, olefines, etcetera, have come from marine animal forms, mainly Foraminifera, such as abound in the older Tertiary formations. It is believed that the more important facts that environ California oil fields will bear out the soundness of this view. Under this conception, oils that contain both asphaltic and paraffin members or equivalents may be regarded as resulting from the mingling of diverse organisms, either within the same bed or the mingling of oils that emanate from different, sometimes alternating, layers, dominated by one or the other of the two principal classes of organisms; but in either case their contribution to the product would be in proportion to their respective elements in the resulting blends, such as are actually found in the field.

As examples of the third class of oils may be cited some, but not all, of the oil north of Santa Paula, Ventura County, and about Sulphur Mountain, and some of that from the Puente Hills. Other examples may be found along the coast, at Summerland, Carpenteria, and other points, already referred to.

In explanation of the occurrence of this third class it may be well to recall the fact, already well known, that in the thick bodies of siliceous shales in many of the oil districts of the State, which for the most part are diatomaceous, there are numerous calcareous beds in which are found the remains or traces of Foraminifera, etcetera; and in other cases, where calcareous strata, and therefore animal organisms, predominate, as in the Eocene formations, there exist siliceous layers with remains of diatoms or other vegetable forms. Such conditions may have been the basis of the following suggestion by F. W. Clarke:[29]

> "These remarks upon the oceanic sediments at once suggest an intermediate group of hypotheses, which assume a mixed origin for petroleum. Animal matter in some cases, vegetable matter in others, or both together, are supposed to be the initial source of supply. . . . Some oils, again, are supposed to be of mixed origin, and it would seem probable that the last class is the most common. Ideas of this kind have repeatedly been enunciated with reference to American petroleums," etcetera. . . .

Exceptional or rare types of oil should each have its special source material and an explanation suited to its character and occurrence.

[29] Clarke: (1924.) Data of Geochem. Bull. 770, U. S. Geol. Surv., p. 753.

Among such may be included the unique type of oil found at "Oil City," in the Coalinga district, coming from the supposed Cretaceous beds, called the "Moreno formation," but here referred largely to the Eocene.

Not far from the locality in question lignitic and carbonaceous beds occur in the base of the Eocene, which horizon at "Oil City," while hidden by overlap, lies stratigraphically just below the oil-yielding strata which in the original description was classed as Eocene.[39] This view of the matter is here revived in consideration of the peculiar character of this oil, with its content of *benzol, toluol, xylol,* etcetera, which seems to ally it with coal-tar products rather than with the ordinary types of California oil. However, in the Eocene shales of this locality, as well as in the underlying Cretaceous, foraminiferal remains are quite abundant.

Among the rarer types of oil found in California are those connected with the quicksilver deposits, which may have arisen from the older Cretaceous beds through a degree of metamorphic action often seen here. Interesting examples of the near approach of the two leading types of California oil in the same field, as well as of the mixed oils, may be cited from the southern province. In the Olinda field extensive beds of asphaltic sand cover the surface in places, and heavy asphaltic oil has been produced by the wells drilled on and near them. Not far away, on the northern border of the field, the oil coming from the Lower Puente shale is of light gravity, greenish in color, and resembles oil of the Ventura type, to which the analyses thus far seen would seem to ally it. Other examples of such proximity are found in some of the fields north of the Santa Clara Valley, as in the Saltmarsh and Wheeler canyons, and on some of the tributaries of the same.

Questions as to the chemical processes and the geophysical factors involved in the elaboration of petroleum in nature from any class of organic matter belong to the province of chemistry or geochemistry and might be passed over as sufficiently covered for the present in the quotations following, yet a few notes seem to be required here.

Source Material of Petroleum

None of the writers who have advocated the origin of California petroleum from Diatomaceæ have attempted to discuss the exact nature of the source material, or have even referred to the oily or waxy matter contained in the diatoms, as essential ingredients. However suitable such substances may be as a possible source of petroleum, it has not been shown that other forms of matter in these organisms should be excluded from

[39] Anderson: Proc. Calif. Acad. Sci., 3d ser., vol. II, pp. 166-167.

our consideration. May not the organic tissue encased within the siliceous skeleton also have contributed to the formation of oil, and would not such tissues form an aggregate more nearly commensurate with the oil supplies than that of the oily or waxy matter?

In the diatomaceous peat usually proposed as the environment of petroleum origin, by such theory, the humic elements greatly preponderate and entomb the diatoms and other associated forms in a matrix that preserves them from total decomposition and loss by developing toxic conditions fatal to biochemical decay, and for some cases the theory may be sound. But in California the diatomaceous deposits are generally without any peaty or humic matter, and swamp conditions have never been claimed for them and can not be invoked in explanation of the origin of petroleum here. It could, perhaps, be shown, however, that the toxic condition necessary to preserve the organic tissues from total biochemical decomposition had been developed under the marine water environment in which the accumulation has taken place, or that such toxic condition was really not at all necessary for their preservation. Perhaps the waxy or oily matter itself served this purpose, if it existed in sufficient quantity.

Historical Notes

GENERAL STATEMENT

All that has been written bearing upon the origin of California oil can not be reviewed here, though the pertinent views of some of the earlier writers can not well be omitted.

S. F. PECKHAM

Peckham, who was primarily a chemist, was very clear and positive in his belief that the oil of California was of an animal origin, and he especially stressed the nitrogenous content of the oil as a proof of its animal source.[31] But there can be no doubt that Peckham was more familiar with the oils and the districts of Ventura and Los Angeles counties than with those of other parts of the State, and in later years he greatly modified his earlier statements as to the origin, as may be seen from a study of his several papers.

C. F. MABERY

This noted chemist, like Peckham and Dr. F. Salathé,[32] was clear in his belief that the oil from Torry Canyon and neighboring districts, as far

[31] Peckham: (1868.) Proc. Am. Phil. Soc., vol. 10, p. 447, etc.
[32] Salathe: (1896.) Calif. State Min. Bur., 13th Rept., p. 656.

as their analyses extended, was of an animal origin. The following statements of Salathé are representative of all:

"In 1892 I began an investigation on the hydrocarbon series constituting the Ventura County crude oils, which I found to contain invariably from 0.75 per cent to 3.5 per cent of nitrogen. . . . The result was the identification of a number of organic bases of the Pyridin and Chinolin series, which heretofore were only found in the so-called animal tar from the distillation of animal cadavers and bones. The presence of these organic bases in the California petroleum indicates, therefore, clearly the origin of this petroleum from animal matter, furnished by the slow decay of a marine fauna," etcetera. . . .

Mabery says concerning the oils with which he was most familiar:[33]

"With reference to the source of limestone oils, the evidence is all in favor of animal origin, and the same is true of California oil, although its formation is far more recent than that of others. Texas petroleum has not been sufficiently studied in relation to its occurrence and composition, but it is evidently of more recent origin, like California oil." . . .

Other quotations from these writers will be given later in this paper.

J. D. WHITNEY

Prof. J. D. Whitney, former State Geologist of California, was accustomed to speak of the white shales of the Tertiary in the Coast ranges as the "bituminous slate formation," the lithologic character of which he analyzed only in part. In discussing the supply of petroleum in California and its availability for commerce, he says:[34]

"The great bituminous slate formation, of Tertiary age, extends through California, from Los Angeles as far north as Cape Mendocino. No doubt it contains bituminous matter enough to supply the world for an indefinite period, could this be made available without expense. But it will be observed that the strata of this formation, all through the region south of the Bay of San Francisco, are turned up at a high angle, in this respect occupying a very different position from the oil-producing beds in the Eastern States." . . .

However erroneous Whitney's views may have been as to the structures of the Tertiary strata, or of this bituminous formation, in different parts of the State, there can be no doubt that he regarded them as the source of vast quantities of bitumen, and that if oil was ever produced in commercial quantities in California its source must be in the bituminous slate formation."

[33] Mabery: (1906.) Jour. Am. Chem. Soc., vol. 28, p. 428.
[34] Whitney: (1865.) Geol. Surv. Calif., vol. i, pp. 117, 126, etc.

Continuing the discussion, in a later paragraph, he says:

"Whether the asphaltum of California is derived from the thickening, or oxidation, by exposure to the atmosphere, of exactly the same substance, chemically speaking, as that which is called petroleum in Pennsylvania, is a matter for chemical investigation. In the light of the facts and considerations just presented, it does not appear to be economically important that it should be settled at once." . . .

Later on, page 126 of this report, speaking of "bituminous slates" near Santa Barbara, Whitney states:

"The slates are black and highly bituminous where the outcrop stripes the sea, three miles to the southwest of Carpenteria, and large quantities of tarry asphaltum flow from them. For a mile or more along the shore the banks abound with it, and it saturates the beach sand and flows down into the sea. Sand, pebbles, shells, and wood are cemented into a hard mass by it, the cement being nearly as solid as the rock itself. Near the old works the strata are almost vertical," etcetera. . . .

"These bituminous slates extend along the base of the Santa Inez range to the east, and were explored by our party as far as Gaviota Pass, about 45 miles from Carpenteria; they continue beyond this, but it is said not as far as Point Conception." . . .

Continuing his reconnaissance northward, the bituminous slates were repeatedly noted, as at Foxin's, Atascadero Ranch, etcetera, and regarding the latter point he makes the following observation:

"To the east of the same camp a light clay slate occurs, with a variable strike and dip; this was presumed to belong to the bituminous slate series. These slates were, in places, much silicified and were associated with the light, infusorial rock, although the relative position of the two sets of strata was not determined." . . .

These quotations from Whitney's report by no means exhaust his references to the bituminous slates of the Miocene, or to their association with "infusorial rock" and other siliceous beds in the Coast ranges. They are enough, however, to indicate that he was aware of their lithologic character and of their bituminous nature, and that he regarded them as the source of a vast amount of such material, though he does not in his earlier work refer these bitumens to any definite class of organisms other than "infusoria," by which he clearly means only diatoms. That by "infusoria" Whitney clearly meant Diatomaceæ is evident, as appears in the quotations which follow, taken from a treatment of the matter published in 1867. This fact has generally been overlooked by later writers on the origin of oil in California.

In this paper Whitney discusses the "Fresh-water infusorial deposits

of the Pacific coast and their connection with Volcanic Rocks."[35] In this it is evident that he meant to include under "Infusoria" nothing other than the Diatomaceæ and allied forms, with which these rocks abounded and of which they are chiefly composed. The paper contains an extended description of the fresh-water lake deposits found in many parts of the Great Basin and other regions of the West, as in Oregon, Nevada, and California. Of these he says in part:

"The white material, of which some of the more prominent localities have been indicated above and which is well known to explorers under so many names, as already mentioned, is in reality chiefly of a siliceous character and made up, to a large extent, of organic bodies of microscopic dimensions, infusoria or Diatomaceæ. The mode of occurrence of these fresh-water infusorial deposits in California and on the Pacific coast in general is very simple. They are accumulations of organisms which have been collected at the bottom of the lakes, or in the lakelike expansions of rivers, in which they grew. The growth took place at a time when volcanic agencies were busily at work, giving rise to accumulations of ashes, pumice, and other materials. . . . . . "The infusorial deposits of Central California—I now refer to those of fresh-water origin and connected with volcanic masses—are all situated in such positions as to show that they were formed and deposited in shallow water," etcetera. . . .

"In conclusion, it may be remarked that the marine infusorial rocks of the Pacific coast, and especially of California, are of great extent and importance. They occur in the coast ranges from Clear Lake to Los Angeles. They are of no little economic importance as well as of scientific interest, since, as I conceive, the existence of bituminous materials in this State, in all their forms, from the most liquid to the most dense, is due to the presence of infusoria, the proof of which statement I will, at some future time, endeavor to set before the Academy."

Unfortunately, it does not appear that Whitney ever carried out his intention to prepare a more complete and formal statement of his theory of the origin of California oil from Diatomaceæ, which, if he had done, would have put the matter definitely at rest and established for himself, without question, the credit of making a valuable contribution to the subject of the origin of petroleum. This he did, of course, but only in an introductory way and in a few paragraphs, whereas others have devoted pages to the enlargement of the same view. Singularly enough, as the matter was left by Whitney, other and subsequent writers who have attempted to interpret his views have stated the matter contrary to fact and credited him with views that he evidently did not entertain. Edward Orton,[36] in reviewing the current theories as to the origin of petroleum, says:

[35] Whitney: (1867.) Proc. Calif. Acad. Sci., vol. iii, p. 319.
[36] Orton: (1888.) Geol. Surv. Ohio, vol. vi., p. 66.

"Professor Whitney has expressed the belief that all the bituminous minerals of California, including asphalt and petroleum, are derived from the remains of infusoria in mineral limestones, but he has not expanded this view into any formal statement." . . .

S. P. Sadtler, in reviewing this subject in 1897, says, in part:[37]

"The belief in the animal origin of petroleum has had advocates equally positive and persistent. In this country, J. D. Whitney, the former State Geologist of California, and T. Sterry Hunt, who was well acquainted with the Pennsylvania and Canadian oil fields, were its chief advocates." . . .

Hans Hofer, discussing the same subject in 1914, says, regarding the animal origin of oil, that[38]

"In North America it found in Whitney, for the petroleum of California, and the brilliant Sterry Hunt, for the oil deposits in the ancient limestones of Canada, Pennsylvania, and Ohio, its most influential advocates, with whom others allied themselves." . . .

These quotations are enough to indicate the interpretation that has usually been put on the published views of Whitney regarding the origin of California oil, and which have served to obscure his real belief, notwithstanding his own clear statement of the matter.

Another thing that tended to obscure Whitney's real views on this subject was the fact that he had invited S. F. Peckham, a notable advocate of the animal origin of oil, to contribute data of a technical nature regarding California oil to Volume II of the Geology of California.

This report was written before 1871 and was published in 1882. Later on, Peckham's own views became much modified, after further acquaintance with the California oil fields.

Peckham's earlier view as to the origin of California petroleum is well illustrated in the following quotation[39] from a paper published in 1868:

"I am convinced that the remains of animal life have contributed much more largely to the formation of petroleum than has generally been supposed, and, further, that the different varieties of petroleum are largely due to the varied forms of animal life existing during the different geological epochs to which the rocks belong and from which the oil primarily issues. . . .

"This opinion is further strengthened and confirmed when we find in rocks of Tertiary age, in which fossil remains of the higher marine animals are found in abundance, a petroleum comparatively rich in nitrogen, of unstable constitution, and undergoing decomposition in a manner similar to putre-

[37] Sadtler: (1897.) Proc. Am. Philos. Soc., vol. 36, p. 97.
[38] Hofer: (1914.) Trans. Am. Inst. Min. Eng., vol. 48, p. 483.
[39] Peckham: (1868.) Proc. Am. Phil. Soc., vol. 10, pp. 445-462.

faction. Such is the character of the petroleum issuing from the Miocene of the Coast Range of southern California."

Concerning the oils of the Sespe region, Peckham writes in 1883-1884:[40]

"The exceedingly unstable character of these petroleums, considered in connection with the amount of nitrogen that they contain and the vast accumulation of animal remains in the strata from which they issue, together with the fact that the fresh oils soon become filled with the larvæ of insects to such an extent that pools of petroleum become pools of maggots, all lend support to the theory that the oils are of animal origin." . . .

In a paper written in 1897 Peckham's views became somewhat altered, as is shown from the following extracts:[41]

"I have lately examined California petroleums more closely than I ever had before. I have distilled off the lightest portions from some of Wheeler's Canyon green oil that I took from the canyon in 1866. . . .

"One hundred miles due north of this coast, on the other side of the Coast ranges, I have examined some of the most extensive veins of asphaltum yet discovered. They have been traced across the country for miles and have been mined to a depth of more than three hundred feet. . . .

"These asphaltum veins lie on one side of and irregularly parallel with a stratum of sandstone which, like all the strata of that region, stands nearly vertical. Along this sandstone stratum bitumen exudes for a long distance. Against it and on the other side of it rests a bed of infusorial earth, at least 1,000 feet in thickness, in some places saturated with bitumen, but for the most part clean and white. These formations extend across the country parallel for miles with the general trend of the Coast ranges. . . .

"For myself, the longer I study the subject and the wider my experience becomes, the less I am prepared to assert that any formula is capable of universal application. I would therefore suggest that, as we now find them, bitumens are in some instances still where they were originally produced by a process of decomposition of animal remains that is at present being illustrated on a small scale in the shallow bays of the Red Sea. Further, that other deposits contain primary distillates from the vegetable and animal remains inclosed in the geological formations that have been invaded by heat, steam, and pressure in the past periods of the earth's history; and, finally, that in some instances as we know them bitumens have been transferred and stored by a secondary invasion of the bituminous deposits by heat, steam, and pressure." . . .

SUBSEQUENT WRITERS

Without reviewing here the history or development of the Diatom Theory of petroleum origin, its importance in California warrants a few of the earlier references in this connection.

[40] Peckham: (1883-1884.) Tenth Census Rept., vol. x, p. 69.
[41] Peckham: (1897.) Proc. Am. Phil. Soc., vol. 36, p. 154.

Bernard Bienfield writes in 1897 in part as follows:[42]

"All the California asphalts themselves, and probably those of the West Indies, contain infusorial earth disseminated through the mass of the hydrocarbons. What is more natural to suppose, then, than that the vast quantities of diatoms and protozoa that have left their bony skeletons as infusorial earth have yielded up their organic matter, and especially their contained oil globules, to the formation of asphalt?" . . .

W. L. Watts, an early oil geologist of California, after reviewing the current theories as to the origin of petroleum, in 1900, suggests:[43]

"It is not the larger animals only which are to be regarded as a probable source of petroleum. The corals and microscopic Foraminifera and diatoms, the skeletons of which in some places are the principal constituents of strata hundreds of feet in thickness, must be regarded as contributing no inconsiderable quota of hydrocarbon material from which petroleum might be formed." . . .

F. M. Anderson, in discussing the oil-bearing formations of western Santa Barbara County in 1904, after referring to former writers, says in part:[44]

"In all of the important petroleum districts of this region organic remains of microscopic size are found in sufficient numbers to support the view of an organic origin for the bitumens. Diatoms, Foraminifera, and Radiolaria occur in enormous numbers in some of the strata and very often in strata saturated with petroleum. Sufficient notice has not yet been taken of this fact." . . .

This author furthermore pointed out the fact that the only class of organisms that had left remains in masses at all commensurate with the oil supply of these districts was that of the Diatomaceæ.

It has been the habit of most writers on this topic during the last two decades to attribute the Diatom Theory to later writers, namely, to Dr. Ralph Arnold,[45] or to this author and his collaborator, Dr. Robert Anderson.[46] It is, of course, true that these two writers gave a somewhat extended statement of the matter, together with considerable information as to the organic contents of the bituminous shales of the Miocene, or of the so-called Monterey shale—more complete, perhaps, than any writer immediately preceding them—and also stated in specific terms their belief that much of the oil of western Santa Barbara County is indigenous in the Monterey group.

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[42] Bienfield: (1897.) Municipal Engineer, vol. xii, pp. 271-282.
[43] Watts: (1900.) Bull. 19, Calif. State Min. Bur., p. 202.
[44] Anderson: (1904.) Bull. Geol. Soc. Am., vol. 15, pp. 581-582.
[45] Arnold: (1907.) Bull. 321, U. S. Geol. Surv., pp. 27-29, etc.
[46] Arnold and Anderson: (1907.) Bull. 322, U. S. Geol. Surv., pp. 109-10.

As Arnold (Bulletin 321) refers to the fuller discussion of the subject in the later publication which is the joint work of himself and Robert Anderson, it is fair to assume that he shares the credit of these statements, whatever their value, with the junior author of Bulletin 322. We therefore quote from the joint report of these writers in their discussion of the diatom origin of oil in California. On pages 109 and 110 we read:

"There is no doubt that the petroleum of the Santa Maria district is indigenous to the Monterey shale. Bitumen is a characteristic part of that formation throughout its wide extent, over an area covering a hundred square miles, and there is no other formation but the Eocene shales in which it is characteristic, . . . The decision is therefore unavoidable that some ingredients of the Monterey shale gave rise to the oil, and the question arises what these were. . . .

"The writers are strongly of the belief that the petroleum was derived largely from the minute organisms, especially the plant organisms (diatoms), which are present in such abundance in these shales. The chemists Peckham and Clarke believed that the nitrogen present in the California oil proves its origin from animal substance. But it is not necessary to consider that this petroleum originated entirely from either animal or vegetable matter; it is more probably the product of remains of both kinds combined, much of the nitrogenous material being furnished by animal tissue. . . .

"Other small organisms of a low order present in the Monterey shale besides the diatoms are Foraminifera and Radiolaria, both orders of marine animals. . . .

"The fact that the limestone and calcareous shale of the Monterey are usually very bituminous suggests the conclusion that the Foraminifera were great oil-formers, inasmuch as these rocks are thought to be made up largely of foraminiferal remains, although the calcareous strata may owe their petroliferous character to their porosity. . . .

"It is certain that there was a sufficiency of organic material included in the Monterey deposits to give rise to a vast quantity of petroleum, as is proved by a rough estimate based on low calculations of the amount of such material present." . . .

Then follows a brief calculation of the possible oil content of the shale, which seems to be sufficiently impressive and which is no doubt trustworthy. In this text the writers do not claim credit for first proposing diatoms as a possible source of oil, but, on the contrary, they refer to the then recent studies of Albert Mann, as well as of David White and others, who had suggested diatoms as a possible source of oil. Nor did the writers of Bulletin 322 attempt to give any complete bibliographic notes on the subject, which may have been impracticable.

For the purpose of extending the references to other and earlier writers outside of California, and to indicate who may have been the

first to propose Diatomaceæ as a possible source of petroleum, the following notes and references are taken from the general literature.

General Literature

While we are primarily concerned only with the origin of oil in California and with the theories pertaining to it, the subject has a wider importance that deserves recognition. The discovery of diatoms as a probable source of petroleum, not only in California, but in any part of the world, appears to have first been made by Whitney in California. A careful search of the literature on this subject, including a number of the more important bibliographies, reveals the fact that no writer appears to have preceded him in the suggestion that petroleum might have been derived from Diatomaceæ. As a working hypothesis for California, he must be admitted to have led all others, since his suggestion dates back to 1867 or earlier.

Boverton Redwood, in reviewing the several theories that have been proposed for the origin of petroleum, referring to Diatomaceæ, says:[47]

"Kramer and Spilker (1900 to 1902)[48] support the view, first proposed by Witt in 1894, that the waxy matter secreted by diatoms may have contributed directly to the production of petroleum." . . .

The literature containing Witt's account is not available at present, but, if we may trust the statement of L. V. Dalton,[49] Dr. Otto N. Witt, of the Royal Technical High School, Berlin, in a short article on the origin of petroleum, suggests that[50]

"Microscopic water plants might have contributed to mineral oils even more largely than more highly organized vegetation." . . .

It is not apparent from the literature that these suggestions of Witt, Kramer, and Spilker have attracted any attention among geologists, or to have been taken seriously as proposing an adequate source of oil.

In California, where diatomaceous deposits are abundant and associated with petroleum, the writings of Witt, Kramer, and Spilker have generally been inaccessible. In fact, they received almost no attention in this country until they were reviewed by F. W. Clarke.[51] Concerning the diatom theory, he writes as follows:

"In 1899 A. F. Stahl and, independently, G. Kramer and A. Spilker called

[47] Redwood: (1906.) Petroleum and its products, vol. I, p. 261.
[48] Kramer and Spilker: (1899.) Bericht. Deuts. Chem. Gesells., vol. 32, pp. 2940-2959.
[49] Dalton: (1909.) Econ. Geol., vol. 4, p. 617.
[50] Witt: (1894.) Prometheus, vol. 5, pp. 349-350.
[51] Clarke: (1908.) Data of geochemistry. Bull. 330, U. S. Geol. Surv., p. 638.

attention to a possible derivation of petroleum from diatoms, which abound in certain bogs. These organisms, according to Kramer and Spilker, contain drops of oily matter, and from diatomaceous peat a waxy substance, resembling ozokerite, can be extracted. The theory based upon these data is briefly as follows:

"A lake bed becomes filled in time with diatomaceous accumulations, over which a cover of other growths or deposits is formed. By decay of the organic substance ammonium carbonate is produced, which hydrolizes the wax, and from the resulting acid carbon dioxide, carbon monoxide, and water are generally eliminated. Ozokerite is thus formed, which, at moderate temperatures and under pressure, becomes converted into liquid petroleum." . . .

"Kramer and Spilker's views have not met with very general acceptance, but they seem to contain elements of value. H. Potonie's hypothesis, for example, seems to be a broadening of Kramer and Spilker's." . . .

These suggestions of Stahl, Kramer, and Spilker in 1899 appear to have been taken by Clarke as the first to definitely propose diatoms as a source of petroleum, starting from the known secretions of the diatoms themselves. Whitney's suggestion was based chiefly on inference arising from the known association of the petroleum, or bitumens, with the diatomaceous deposits. His writing antedates that of Kramer and Spilker by over 30 years.

Conclusions

From the foregoing notes and references to the earlier literature regarding the occurrence and origin of bitumens in California, it would appear that the several oil districts have made their own suggestions as to the strata of origin and the source materials from which their petroleum and other forms of bitumen have been derived.

It was early discovered by Whitney (1865 to 1867) that in the coast regions of California, north of the Santa Ynez range, a single class of organisms was not only dominant in the "bituminous slates" of the Miocene, but that these organisms had intimate geologic relationship to the bitumens, and he believed that the bitumens throughout California owed their existence to the presence of Diatomaceæ in the shales, the "proof of which" he intended to have set forth in a formal theory. He apparently meant to apply this theory to all of the oil found in California.

This theory has since been revived and elaborated and has become the accepted theory as to the source of the great bulk of the California petroleum, probably constituting as much as 80 per cent of the production, past and present. These are the well-known asphaltic oils of this State, in which there are no paraffins or allied substances.

It was likewise discovered by Peckham about the same time (1866 to 1882) that the oils with which he was most familiar, namely, those

south of the Santa Ynez range, in Ventura and Los Angeles counties, had a large nitrogen content and, besides, contained other characters that seemed to prove their origin in animal remains. Peckham not only believed this to be the source of the oils named by him "venturaite," but he attempted to apply his theory to all of the oils produced in California, which attempt he later abandoned. Owing partly to the fact that he attempted too wide an application of his theory and partly to the fact that oil of the Ventura type soon formed only a small percentage of the State's production, the theory and the proof of its essential soundness has almost been lost sight of among geologists, although it appears to be, nevertheless, valid, if restricted to the type of oil designated by him as "venturaite," in which there is a large percentage of the unsaturated hydrocarbons, olefine and naphthene, etcetera.

Whether Peckham really recognized the existence of Foraminifera as an adequate source for the oil supply is not clear, but, at all events, others have since done so, and the theory should be regarded as correct within the limits of its proper province.

Oils characterized by both asphaltum and paraffin (or olefine, naphthene, etcetera) should be regarded as mixtures, or blends, whose source materials have been both plant and animal. These, perhaps, constitute the second largest class of the State's production, though no exact figures are at present available.

Oils of the exceptional or unique types, such as those carrying benzol, toluol, xylol, etcetera, have had their origin in materials suited to their character. The so-called "Moreno formation," with which oils of this type have been associated in the Coalinga district, has not yet been clearly defined, either as to its stratigraphic position or as to its areal boundaries. It should be, in part at least, Eocene in age and not wholly Cretaceous. In this district the Eocene formations at their local base are characterized by lignitic and carbonaceous beds, and such may possibly be the source of the oils in question, found especially in the "Oil City" field, north of Coalinga.

But little oil carrying true paraffin is known, though small percentages of paraffin have been reported in some of the oils from the Coalinga district which also carry a much larger per cent of asphaltum. The source of such oils is not actually known, though presumably the source material is mixed, probably plant and animal remains together.

Seaweed has been proposed as a source material for some California oil, especially in the San Joaquin Valley, the chief support of which view is the iodine found in waters from the oil fields. Its actual connection with any of the oil deposits can not now be stated, and in fact was

never shown, and no important occurrences of such material or evidence of its existence has been found in the Tertiary formations about the oil fields referred to, nor does it appear to have been generally accepted by oil geologists in California, if at all.

The source material of the rarer types of oil found in California need not be considered here, especially as their analyses are lacking and the exact horizon and geologic relations are not known.

The theory proposed in this discussion, that the asphaltic oils of California have been derived from Diatomaceæ and other allied forms of plants, found chiefly in the Miocene, and that the so-called paraffin oils of the Ventura type and those with true paraffin, if such exist, have had their sources in animal remains, such as Foraminifera, seems to conform to the facts maintaining in many other regions of the world, especially on the American Continent.

General Application of View

How the view here suggested, namely, the derivation of asphaltic oils from vegetable matter and of oils containing paraffins (or olefines, etcetera) from animal matter, would apply to other oil regions outside of California is not fully known, since many other organic sources than those of California, as well as many other types of oil, might be shown. Doubtless in other oil regions of the world much evidence seemingly contradictory to this view could be found, but in such cases of apparent conflict are the essential facts and geologic relations always known?

If the course of migration could be correctly followed in all cases, it is very probable that much conflict of evidence would disappear. Transformational migration of oil must greatly obscure or completely conceal the real source, and doubtless along lines of anticlinal uplift, often resulting in fractures, the vertical movement of oil is often greatly facilitated, and the extent of such movement may be great.

Most of the earlier discussions of geologists as to the origin of petroleum have been without proper limitations, either with regard to the type of oil referred to or with regard to the organic matter available for it. Many types of oil are known to chemists, and probably as many classes of organisms and of deposits from which oils might result, as has been suggested before. As for asphaltic oils, there are many regions in which they have been definitely traced to accumulations of some form of vegetable debris buried in associated strata. For example, the asphaltic oils of Trinidad, of Burma, of western Kentucky, and many other regions have been assigned to a vegetable origin, not always unicellular or microscopic. Many types of vegetation have been suggested.

On the other hand, the oils from the Trenton limestones of the Middle West contain chiefly paraffin hydrocarbons, though they also contain unsaturated series as well. There can be no question as to the animal origin of the limestones themselves. The Cretaceous oils of the Rocky Mountains region, as well as of the great Sabine Uplift of eastern Texas and Louisiana, can be traced either to limestones or to chalks underlying, or otherwise associated with the oil strata. The same can be said of many of the fields of the Mid-Continent region, if not all of them. While the beds that actually contain the pools are not always calcareous, many of them are so, and perhaps in all cases, if the beds could be followed down dip, they might be found to pass by transitions into areas of limestone.

In many of the oil shale deposits of the West, where conditions are necessarily simple and no question can arise as to the geologic relations or the source of the oil, those deposits from which oils of the paraffin series have been obtained show on microscopic examination an abundance of minute animal forms, including Crustaceæ, such as might well be taken as the source of the so-called "kerogen" which they contain. This is true, for example, of the deposits at Elko, Nevada, and of other deposits of the Green River shales observed by the writer. Similar facts have been observed also in the Mono basin, where oil has been found in seepages. The fact that the oil extracted from many of these paraffin-bearing shales also contains nitrogen, sulphur, and the "pyridine compounds" may be taken as further evidence of animal origin, notwithstanding the statements of Winchester[52] that in the Green River formation the oil "is largely obtained by the destructive distillation of partly bituminized vegetable matter."

Although the oils of the Pennsylvania region have usually been regarded as of vegetable origin, may it not be otherwise? Hofer classes these deposits with those of Ohio and Canada, as illustrating the animal origin[53] of petroleum, and in discussing this subject he continues:

"Many American geologists and chemists, like Lesley, Newberry, Ashburner, Shaler, Orton, Peckham, Mabery, etc., had already either advocated a common animal or vegetable origin or . . . assigned an animal origin to the nitrogenous California product and a vegetable one to the non-nitrogenous oil of Pennsylvania. The contrary appears, however, to be the truth, since diatoms are found in California and not in Pennsylvania oil fields." . . .

Concerning the source of Pennsylvania petroleum, David T. Day has stated a view somewhat contrary to that usually accepted. The theory

[52] Winchester: (1923.) Bull. No. 729, U. S. Geol. Surv., p. 135.
[53] Hofer: (1914.) Trans. Am. Inst. Min. and Met. Eng., vol. 48, p. 484.

is one proposed by a writer apparently familiar with the geology of these regions, in behalf of which Dr. Day's language is in part as follows:[54]

"General opinion tends to associate the Pennsylvania oils with a vegetable source, and it is against this that I wish to make a few suggestions, based upon the observations of Rev. John M. MacGonigle, formerly a stratigrapher in the employ of the Forest Oil Co." . . .

The theory is thus stated by Dr. Day:

"The uplift which forms the Appalachian chain occurred at the close of the Carboniferous period. This was due directly to heat action. It is, therefore, at least suggested that the petroleums of Pennsylvania owe their origin to the effect of this heat upon the underlying limestones and shales of the Silurian age." . . .

After quoting at length the evidence supplied by his author for this striking theory, Dr. Day continues:

"I believe that this theory of Mr. MacGonigle is more probable than any that has been advanced as to the present condition of oil in Pennsylvania." . . .

Day then proceeds to explain in simpler terms how the oil now held in the Devonian repositories of Pennsylvania could have arisen from the Silurian limestones below, the animal origin of which is unquestioned. Other evidence and testimony to the same effect could be multiplied if these statements seem insufficient.

[54] Day: (1897.) Proc. Am. Phil. Soc., vol. 36, p. 113, etc.

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PRE-CAMBRIAN GEOLOGY OF THE MEDICINE BOW MOUNTAINS[1]

BY ELIOT BLACKWELDER

(*Read before the Society December 28, 1917*)

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INTRODUCTION

The Medicine Bow Mountains lie south of the Union Pacific Railroad and about 40 miles west of the city of Laramie, in southeastern Wyoming. They extend southward into Colorado. A short alpine ridge, known as the Snowy Range, rising to an elevation of 12,000 feet, surmounts a

[1] Manuscript received by the Secretary of the Society May 26, 1926.

FIGURE 1.—Geologic Sketch Map of a Part of Southeastern Wyoming

broad plateau which varies from 9,000 to 10,000 feet in elevation and is intrenched by canyons. The plateau, partly margined by fault-line scarps, is nearly surrounded by a broad, terraced plain that has been eroded from outcrops of Cretaceous shales by streams and wind.

In spite of its ready accessibility, this interesting range has been strangely neglected by geologists until the last decade. In 1868 Hague[2] made a reconnaissance, noted the general character and distribution of the rocks, and offered a tentative interpretation of the internal structure. Van Hise[3] crossed the range on horseback in three days in 1889 and thereby added some further information regarding the pre-Cambrian rocks. Subsequently the range was visited from time to time by Wilbur C. Knight and his son, S. H. Knight, and perhaps by other geologists; but no detailed work seems to have been attempted and the results of such examinations do not appear to have been published.

In 1917 the writer, assisted by H. F. Crooks, then a student of the University of Illinois, devoted six weeks to a survey of the pre-Cambrian rocks in the central part of the range. During a part of the season he also had the company of F. M. Van Tuyl and S. H. Knight.

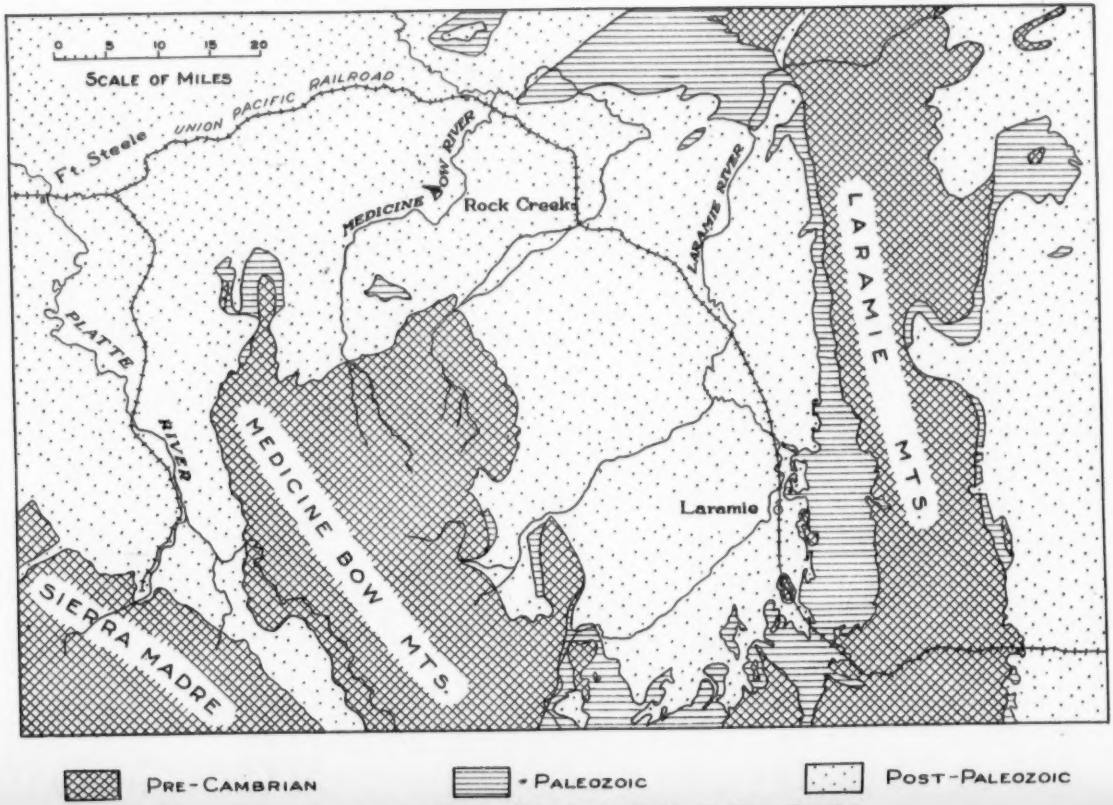
The World War interrupted this work, and Mr. Crooks went to France as a soldier a few months later. The writer presented an outline of the results at the Saint Louis meeting of the Geological Society, but never submitted the paper for publication because he felt the need of more field-work. At the time, it was hoped that Mr. Crooks would be able to return and complete the study himself, but that hope was never realized.

Again, in the summer of 1925, assisted by A. L. Crawford, the writer devoted a month to reexamination of the same district, but the unprecedented rainy season so reduced the available time that certain outlying parts of the district, such as French Creek and Medicine Bow River canyons, were not reached. During the same season J. F. Kemp, in company with S. H. Knight and students from the University of Wyoming, spent some weeks on the eastern side of the range, and J. J. Runner, assisted by students from the University of Iowa, made a detailed study of the pre-Cambrian rocks at the request of the State Geologist of Wyoming. Aside from the brief abstract[4] of the paper read by the present writer at the Saint Louis meeting of the Society in 1917, none of the results of any of these explorations have as yet been published.

[2] Arnold Hague: U. S. Geological Exploration of the 40th Parallel, vol. ii, 1877, pp. 94-111.

[3] C. R. Van Hise: Unpublished notes, summarized in "Pre-Cambrian Geology of North America." U. S. Geol. Surv. Bull. 360, 1909, pp. 837-883.

[4] E. Blackwelder and H. S. Crooks: Pre-Cambrian rocks in the Medicine Bow Mountains of Wyoming. Bull. Geol. Soc. Am., vol. 29, 1918, pp. 97-98 (abstract).



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Showing distribution of pre-Cambrian formations. Adapted from maps by U. S. Geological Survey.

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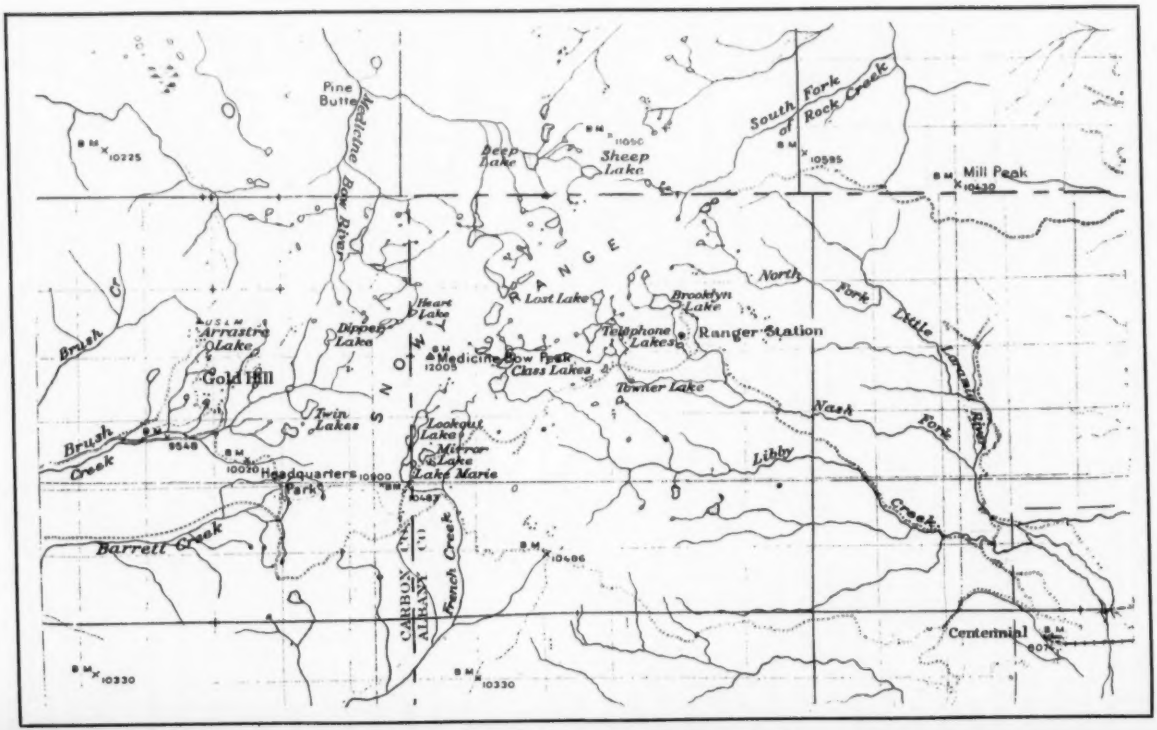

FIGURE 2.—*Map of the Snowy Range and Vicinity*

Adapted from U. S. Geological Survey topographic map, with slight corrections. The small squares are one mile wide.

The general geographic features of the district are represented on figure 3. For greater detail the reader is referred to the contour map of the Medicine Bow Quadrangle published by the U. S. Geological Survey.

Thus far only a few of the more important topographic features of the range have been definitely named. Sheep herders, prospectors, and the rangers of the Forest Service have until recently been the only inhabitants of the plateau. Scarcely any of the mountain summits—not even the high eastern summit of the Snowy Range—have names that are in current use. Likewise, of the 160 or more glacial lakes distributed over the surface of the Medicine Bow plateau, only a few of the largest or most accessible have been named.

Until recently, access to the district was chiefly by trails and a few very poor roads over which wagons could be taken with difficulty. In 1925, however, a good automobile road was completed from Centennial to Brooklyn Lake, and thence southwestward across the range to Brush Creek and Saratoga. There is also a passable road for automobiles to Sand Lake by way of Rock Creek.

As the district is rather generally forest-covered, affording attraction for fishermen and a refuge from the torrid plains of the Central States, its use each year as a summer playground is increasing rapidly.

Outline of the Geology of the District

On referring to the general map, the reader will see that the Medicine Bow Mountains consist of a large anticline in Mesozoic and Carboniferous strata, the top of which has been so deeply denuded that the pre-Cambrian formations in the core are now broadly exposed. The latter comprise many metamorphosed sedimentary and igneous terranes which have been strongly folded and strike northeasterly. They are therefore entirely discordant to the structure of the younger overlying rocks. The pre-Cambrian sedimentary strata are apparently not duplicated by folding, but some complications have been introduced by faulting. There are at least twelve readily separable formations, the aggregate thickness of which is about 24,000 feet. They have been intruded by a few small stocks of granitoid rocks and by many large basic dikes. On either side the sedimentary series is flanked by a gneissic complex. In part this also is of sedimentary origin, but much of it still awaits satisfactory interpretation. In general it resembles the most ancient rocks of northern Colorado and of the Laramie Range in Wyoming.[5]

FIGURE 2.—*Map of the Snowy Range and Vicinity*

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[5] N. H. Darton, E. Blackwelder, and C. E. Siebenthal: Description of the Laramie and Sherman quadrangles, Wyoming. U. S. Geol. Surv. Atlas, Folio No. 173, 1910.

J. E. Spurr, G. H. Garrey, and S. H. Ball: Economic geology of the Georgetown Quadrangle, Colorado. U. S. Geol. Surv. Prof. Paper No. 63, 1908.

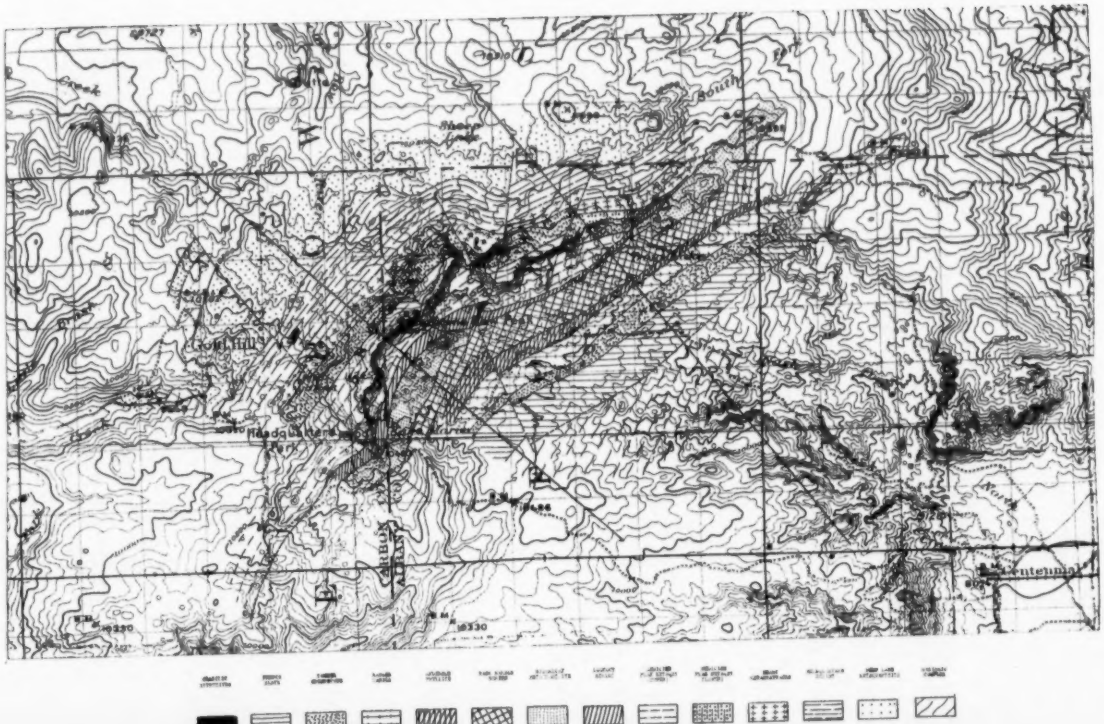

FIGURE 3.—*Reconnaissance geologic Map of the Snowy Range District, Medicine Bow Mountains*
Based on topographic map by U. S. Geological Survey.

In the high, glacier-worn, central part of the mountains, outcrops are plentiful and favorable for detailed study. Over the greater part of the dissected plateau, however, the rocks are largely concealed by glacial drift, soil, and dense forest. In that part of the mountains much laborious groping after hidden outcrops remains to be done before even the general survey of the range may be deemed completed. Even then it will not be possible to work out the sequence and structure with the same degree of assurance as in the axial part of the range.

In the present paper it is the writer's purpose to summarize his understanding of the stratigraphy and structure of the pre-Cambrian rocks. It should serve as a useful basis for the more detailed studies that are already planned by others and will be continued for many years.

STRATIGRAPHY

GENERAL STATEMENT

Although the various stratigraphic units are readily distinguishable, the order of superposition is not yet completely known. For purposes of description it is convenient to recognize a northwest, a central, and a southeast mass.

The northwest and southeast masses are complexes of gneisses, schists, and granites, poorly exposed, difficult to interpret, and not yet much studied.

The central mass is here divided into 12 formations and described in the apparent order from oldest to youngest. In nearly all cases the order of age has been ascertained by studying the various contacts and the primary sedimentary structures, such as ripple-marks, cross-bedding, and change in texture. Within this great sequence no unconformities involving angular discordance have been found; nor is there any visible difference in the degree of alteration suffered by the various formations, except that which is appropriate to their varying chemical composition.

Regarding the geologic age and correlation of these formations, it is too early to do more than express a few opinions. In the absence of trustworthy fossils, the geologist must depend upon physical evidence. Since all the rocks of the Medicine Bow district are more intensely folded and far more metamorphosed than any of the Paleozoic strata in the eastern part of the Rocky Mountain province, it is safe to conclude that they are pre-Cambrian. By the same token they are probably older than the late pre-Cambrian systems represented by the Grand Canyon, "Uinta" quartzite, and Belt series. Lithologically and in degree of metamorphism, the sedimentary formations of the Medicine Bow district strongly resemble such terranes as the quartzite-schist-marble series of the En-

FIGURE 3.—*Reconnaissance geologic map of the Sierra Madre Range, Wyoming.*
Based on topographic map by U. S. Geological Survey.

campment mining district[6] in southern Wyoming, the Red Creek[7] quartzites of northern Utah, the quartzites east of Willard,[8] Utah, the Cherry Creek series of southwest Montana,[9] and the Whalen group of the Hartville[10] district, in eastern Wyoming. If one may look so much farther away, comparison may be made also with the Huronian rocks of the Lake Superior district. The writer therefore suspects that these sedimentary formations are of early Algonkian (Proterozoic) age.

The gneissic series resembles much of the early pre-Cambrian complex in the Laramie Range, to the east, and in parts of northern Colorado, but the age of the latter is still problematical. In general the gneissic complex of the Rocky Mountains has been referred, with some doubt, to the Archean period.

TABLE OF PRE-CAMBRIAN FORMATIONS

	Feet	
15. Basic intrusives.....	....	Dikes of gabbroid and diabasic rocks. (Some of them probably older than number 14.)
14. Acidic intrusives.....	....	Small stocks and dikes of granitic and syenitic rocks, aplites, pegmatites, and quartz veins. (Not abundant and possibly of more than one age.)
13. French slate.....	2,000	Blackish, pyritic slates or phyllites, with thin beds of schistose metaquartzite.
(Probable conformity.)		
12. Towner greenstone.....	900	Schistose basic greenstones, probably derived from pyroclastics and flows.
(Probable conformity.)		
11. Ranger marble.....	2,300	Bluish gray, pure, massive, dense marble, with a few slaty beds and but little jasper.
(Conformity.)		
10. Anderson phyllite.....	1,600	Banded gray and black sericitic and pyritic phyllites, chloritic metadolomites, and talcose schists.
(Probable conformity.)		

[6] A. C. Spencer: The copper deposits of the Encampment District, Wyoming. U. S. Geol. Surv. Prof. Paper No. 25, 1904.

[7] S. F. Emmons: U. S. Geol. Surv. of the 40th Parallel, Descriptive Geology, 1877, pp. 269-270.

[8] E. Blackwelder: The Wasatch Mountains revisited. Bull. Geol. Soc. Am., vol. 36, 1925, pp. 132-133 (abstract).

[9] A. C. Peale: Description of the Three Forks Sheet. U. S. Geol. Surv. Atlas of U. S., Folio No. 24, 1896.

[10] W. S. T. Smith: Description of the Hartville Quadrangle, Wyoming. U. S. Geol. Surv. Atlas of U. S., Folio No. 91, 1903.

	Feet	
9. Nash marble series.....	2,400	Chiefly dense marble, massive to thin-bedded, white to pink or gray, alternating with beds of jasper, chloritic phyllite, striped ferruginous metadolomite, and thin biotitic schists. Some beds contain structures believed to be fossil algæ. The lower part consists largely of massive to slaty gray metargillites.
(Relation unknown.)		
8. Sugarloaf metaquartzite...	1,900	Dense, pure, vitreous, white to bluish rock without partings; very fine texture.
(Conformity.)		
7. Lookout schist.....	1,200	Olive-gray, flaggy mica schist or phyllite, with many thin beds of metaquartzite, a few of brown marble, and one of gray magnetite schist.
(Conformity.)		
6. Medicine Peak metaquartzite, upper member.	3,900	Very massive, coarse-grained, white to greenish rock, with several thin beds of white to purplish conglomerate near the top; a few thin chloritic beds.
(Conformity.)		
5. Same, lower member.....	1,700	Very coarse, massive, violet-gray rock spotted with green cyanite.
(Conformity.)		
4. Heart metagraywacke.....	1,500	Alternation of gray to olive, smoky metaquartzites and chloritic phyllites, much cross-bedded and fine-textured.
(Conformity.)		
3. Headquarters schist.....	±2,800	Largely greenish quartz-chlorite schists, finely laminated; contains thick and thin beds of metaquartzite, metadolomite, and three beds of schistose tillite.
(Probable conformity.)		
2. Deep Lake metaquartzite..	2,000+	Coarse to fine, massive to slabby, gray rock, with a few beds of fine fluvial conglomerate and also scattered pebbles and clay-galls; cross-bedding very regular; concealed beds probably schists.
(Relation unknown.)		

	Feet	
1. Gneissic complex.....	?	Striped and contorted gray to pink biotitic and hornblende gneiss, augen-gneiss, hornblendic muscovitic, and biotitic schists and white silicated marble, complexly injected by pink and gray granites of two or more ages, with their attendant pegmatites, aplites, and quartz veins. (May be in part due to batholitic metamorphism of numbers 2 to 13.)
Total.....	24,200+	

GNEISSIC COMPLEX

The most widespread formation in the Medicine Bow plateau is a complex that contains many types of gneisses, schists, and granitoid intrusives. If there is any ascertainable stratigraphic sequence, it is still unknown. The complex is the country rock on both the northwest and southeast flanks of the Medicine Bow plateau, but it is largely concealed by glacial drift and soil. The best outcrops are along the sides of the canyons which have been cut into the plateau, especially to the south and east of the Snowy Range.

The commonest rocks are striped gray gneisses that are believed to have been mica schists and hornblende schists, along whose planes of cleavage granitic juices have been injected. From the latter, aplitic and pegmatic materials crystallized, forming gray and pink stripes. Some of the latter have been minutely crumpled. The mass has also been intersected by later dikes of pegmatite, aplite, and normal granitoid rocks, which have not been subsequently folded. Field relations suggest that the dikes of gray gneissoid granite are older than those of the pink, unaltered granite and pegmatite. The latter are similar to the acidic intrusives near the Snowy Range and may well be of the same age.

Locally the gneiss contains masses of brownish gray, highly contorted marble[11] and white tremolitic marble[12] interbedded with white quartz-muscovite schist. A coarse-grained pink augen-gneiss forms part of the complex on the south side of Libby Creek Canyon.

In general the gneissic mass is not as well exposed as the great sequence of sedimentary formations to be described later. The writer devoted but

[11] About two miles west of Centennial village.

[12] On the north fork of Little Laramie River, about one-fourth mile below the contact between the gneissic complex and the French slate.

little time to the study of it, and, as its interpretation is more difficult, it still largely awaits description.

At no point has the writer discovered the actual contact between the gneissic complex and the sedimentary formations. It is concealed by glacial drift and soil. The gneisses may be older. In that case they are probably faulted against the French slate, which seems to be the youngest member of the pre-Cambrian sedimentary succession. On the other hand, they may be, in part at least, due to the intense contact metamorphism and injection of the sedimentary formations by a series of acidic intrusions. The problem is still unsettled, but the writer inclines to the former view for reasons set forth on page 646.

FIGURE 4.—*Boulder of dark-gray Gneiss*

The boulder was injected by an older set of pegmatite veins which have been folded, and then intersected by a younger set of undisturbed pegmatite veins. The location is along the Forest Service road, just below the Nash Fork bridge.

DEEP LAKE METAQUARTZITE[12]

Structural relations indicate that this is probably the oldest of the pre-Cambrian sedimentary formations, unless the little-known metaquartz-

[12] The prefix "meta-" will be used throughout this paper to designate rocks derived by complete recrystallization from sedimentary or igneous rocks. Thus, while "quartzite" is sand that has completely cemented with quartz, the same rock recrystallized is a "metaquartzite." Such a rock has developed a granitoid or gneissic texture. It is correlative with schist, gneiss, and marble.

ites in Pilot Knob and Windy Hill are distinct and still older. (See page 627.)

The best outcrops of the typical Deep Lake metaquartzite are in the 11,100-foot mountain northwest of the head of the south fork of Rock Creek, around Deep Lake,[14] and in the vicinity of Gold Hill.

Since the base of the formation is not definitely known, only a minimal estimate of its thickness can be given.

The beds which appear to be lowest in the sequence are coarse, massive, grayish white metaquartzites that take on pale olive or pale brown tints on exposure. The individual grains are commonly from 1 to 3 millimeters in diameter. On the north side of Gold Hill[15] the metaquartzite contains about 80 feet of conglomerate, in which pebbles one-half to 2 inches in diameter are concentrated in beds 4 to 12 inches thick. The pebbles consist entirely of quartz and are not only well rounded but well sorted.

In this lower, massive part of the formation, beds 2 to 4 feet thick are typical. There are many very thin partings of olive-gray phyllite. Cross-bedding on a large scale, with curved and regular laminations, is distinct.

Near the middle of the formation there are some rather schistose white metaquartzites of fine texture, and there is a suggestion that intercalated schists of considerable thickness are present, but are generally too weak to form outcrops.

The upper half of the formation is better known, because it consists almost entirely of metaquartzite and therefore stands out in bold outcrops. The beds vary somewhat from place to place, but the following section, measured roughly on the northwest side of the south fork of Rock Creek, is typical and representative:

	Feet
(Conformable contact with green schists above.)	
16. Metaquartzite, grayish white, becoming schistose above	15
15. Metaquartzite, dark gray, with several 2-inch beds of metaconglomerate that are somewhat schistose	25
14. Metaquartzite, light gray, with 2–3-inch beds of metaconglomerate	25
13. Metaconglomerate, rather coarse, dark gray, probably of fluvial origin	15
12. Metaquartzite, massive, brownish gray	10
11. Metaconglomerate, fine, fairly well assorted, with pebbles one-half to 2 inches in diameter	20
10. Metaquartzite, massive, brownish gray	25
9. Metaconglomerate, thin beds of granite pebbles, one-fourth to 2 inches in diameter	10
8. Metaquartzite, massive	35

[14] Incorrectly labeled "Sheep Lake" on the U. S. Geological Survey map.

[15] About one-half mile northeast of U. S. Landmark 10502.

	Feet
7. Metaconglomerate, like number 9	25
6. Metaquartzite, like number 10	25
5. Metaquartzite, massive, pale gray, with olive-colored schistose partings	225
4. Metaquartzite, very massive, grayish white	120
3. Metaquartzite, partly schistose and poorly exposed	280
2. Metaquartzite, massive, grayish white, with many clay pellets and thin beds of white quartz pebbles	40
1. Metaquartzite, massive, cream to white, very regularly cross-bedded, with plane laminæ in layers 2 to 5 feet thick	100
	995

One of the most characteristic beds in this section is number 1, which has been recognized by its peculiar type of cross-bedding at intervals all along the western side of the range. Bed number 2 is also distinguished by its many clay pellets, or "thongallen," of yellowish olive color. We found nothing resembling this in any other formation of the district. Southwest of Dipper Lake the metaconglomerates of beds number 9 to number 15 appear as a single member about 100 feet thick. In this the pebbles consist entirely of quartz and greenish slate, without granitoid rocks. The pebbles are well sorted, well rounded, rather evenly stratified, and were imbedded in a clean sandy matrix.

In the area between Sand Lake, Sheep Lake, and the canyon of the West Fork of Medicine Bow River, the exposed rocks consist largely of metaquartzites and basic intrusives, but the writer has made only a hasty inspection of them. The metaquartzites are probably to be correlated with the Deep Lake formation. They are mostly grayish white rocks, locally streaked or banded with gray, purple, and flesh pink. They are generally rather strongly cross-bedded and contain white quartz pebbles, one-fourth to one-half inch in diameter, either scattered through the sandy phase or concentrated in thin beds of conglomerate. From such poor outcrops as were seen, it was inferred that the dips are gentle and variable—an impression that is consistent with the great width of the outcrop in that locality.

HEADQUARTERS SCHIST

This is one of the most interesting and distinctive formations in the district, but too soft to give continuous exposures. It outcrops only in low, ice-scoured knolls and in postglacial stream channels in the glaciated heads of the valleys northwest of the Snowy Range. The name is derived from Headquarters Park, which is situated upon the outcrop.

In general the formation consists of greenish gray, chloritic phyllite or schist, with several beds of metaquartzite, glacial metaconglomerate,

metadolomite, and schistose basic pyroclastics. Although the rocks have been recrystallized, they have not lost their more distinctive characteristics. Both above and below, the formation grades conformably into adjacent terranes.

The following complete, but partly concealed, section from the vicinity of Twin Lakes is typical of the formation. It is possible that the section is more or less complicated by minor faults and even by small closed folds, but of this there is definite indication in only a few places. The thicknesses have been calculated from a paced traverse and are only approximate.

	Feet
13. (Covered.) Partly biotitic greenish gray phyllites and schistose flags[16]	350
12. Phyllite, greenish gray, quartz-chlorite rock, finely laminated	500+
11. Metatillite, recrystallized argillite, with many scattered pebbles and small boulders	100
10. (Covered.) Mostly striped greenish phyllites	450
9. Phyllites greenish gray, with one 25-foot bed of impure gray metaquartzite. Locally the quartzitic layers preserve long parallel ripple-marks	150
8. (Covered.) Biotitic chlorite-phyllite in part	435
7. Metaquartzite and phyllite, an alternation of muddy gray metaquartzite, slaty metaquartzite, and quartz schist in three 10-foot beds. Many repetitions	65
6. Metatillite, massive recrystallized bouldery argillite	25
5. Metaquartzite, white to pink rock, with olive slaty partings and scattered granitic pebbles	20
4. (Covered)	75
3. Metaquartzite, grayish white, with layers of striped quartz-chlorite phyllite	25
2. (Covered.) Largely striped greenish gray phyllite, with scattered pebbles	450
1. Metatillite, boulder slate. (Rests with apparent conformity on the massive metaquartzite of the Deep Lake formation)	125
Total	2,770

Other members have been found farther northeast. Thus, on the head of West Fork of Medicine Bow River,[17] the basal member is a green schist that has the fragmental structure and mineral composition of a metamorphosed basic pyroclastic rock. Although mashed, the fragments in the agglomerate are still clearly recognizable. This appears to be a local member, but it is 600 feet thick at the point examined. Northwest

[16] Bearing a suggestive resemblance to the Woodside formation (Lower Triassic) of southeast Idaho.

[17] About one mile northwest of Heart Lake.

of Dipper Lake, and again north of Heart Lake, a member consisting of alternate pure and jaspery blue-gray metadolomite, gray jasper, and quartz-mica schist forms part of the zone corresponding to bed number 2 of the section above.

Field relationships indicate clearly the presence of a basal and two median boulder slates that are almost unquestionably of glacial origin. They consist of massive, wholly unstratified, gritty metargillite, with scattered pebbles and boulders of all sizes up to 5 feet in length. The pebbles are not well rounded nor sharply angular, but are soled and subangular. Owing to the fact that the schistose matrix adheres tightly

FIGURE 5.—*Schistose Tillite*

Boulders of gneissoid granite embedded in a schistose matrix. The location is southwest of Twin Lakes.

to the pebbles, we were unable to find any striated surfaces; but the conditions for their preserval are so bad that this should hardly be expected. The matrix is just such a rock as the anamorphism of a tillite ought to develop—a granular recrystallized rock, composed of quartz, feldspars, muscovite, biotite, chlorite, magnetite and so forth. Although locally schistose, it is generally massive and of a dull, slightly olivaceous gray color. The pebbles of the two lower beds consist largely of pink gneissic granite, with a few of massive gray granite, gray metaquartzite, and olive-gray chloritic schist. The pebbles of the uppermost bed con-

tain almost nothing but the pinkish granite. The sources of these rocks have not been definitely recognized.

Intimately associated with the boulder beds are finely banded phyllites that have all the characteristics of anamorphosed varve silts (glacial lake sediments). They are now greenish gray chlorite-sericite phyllites

FIGURE 6.—*Crumpled, laminated Schist of the Headquarters Formation*

It probably represents a deposit of varve silt of glacial origin. The location is north of Twin Lakes.

with scattered crystals of biotite, magnetite, etcetera. The banding is very regular, in widths of 1 to 5 millimeters. Light and dark laminæ, very similar to the summer and winter layers of the Pleistocene glacial clays, alternate in regular order. The lighter layers contain more quartz

and are coarser, while the dark layers contain more mica and are much finer in texture. These striped schists are especially prominent in bed number 12 of the section—above the third metatillite. Some of the striped schists overlying each of the metatillites contain scattered pebbles and even small boulders, like those in the metatillites, but they do not include any continuous beds of conglomerate. Such scattered pebbles may have been carried out by floating ice. The metatillites were recognized by Mr. Crooks in the lower part of Rock Creek canyon, also, but their relations there are unknown.

Other members of the series are interbedded dark-gray schists and thin, impure metaquartzites that are the anamorphic equivalents of such formations as the Montana series of Wyoming, or of some of the upper Cretaceous deposits of the California coast ranges. Many of them still show the fine cross-bedding of the small festoon type, well preserved ripple-marks, and small erosion channels.

HEART METAGRAYWACKE

The great metaquartzite series of the Snowy Range may conveniently be divided into two formations, although three have been differentiated on the map. Of these the older is named for Heart Lake, which is situated upon its outcrop. It consists largely of schistose graywackes and schists, and thus represents a transition from the slaty series below to the pure, massive metaquartzites above.

No full section of this formation was measured, although there is a possible opportunity north of the gap in the Snowy Range. The best outcrops were found around the northeast end of the Snowy Range, but they are somewhat complicated by small faults and perhaps by minor folds. By piecing scattered outcrops together, the following general sequence was compiled:

	Feet
(Conformable upper limit.)	
17. Metagraywacke, massive, gray to pale olive-colored, with beds of olive gray schistose metaquartzite. Muscovite, biotite, and feldspars are abundant, in addition to quartz	250
16. Metaquartzite, rather schistose, dull grayish white	100
15. Metaquartzite, massive gray white, tinged with violet and drab colors	125
14. Metaquartzite, coarse olive gray, with thin beds of pale olive schistose metaquartzite	90
13. Metagraywacke, gray striped rock	20
12. Metagraywacke, massive olive gray to smoky gray, faintly banded	15
11. Metagraywacke, slaty dark-gray rock, with pyrite cubes	100
10. Metagraywacke, dark gray, spotted and streaked with light gray	10

	Feet
9. (Covered.) Mostly dark schistose metagraywackes and chloritic schists	270
8. Metagraywacke, smoke gray, spotted; well cross-bedded in small festoons	30
7. (Covered.) Mostly thin-bedded metagraywackes, with phyllites	35
6. Metagraywacke, impure, smoky gray, with spatulate current marks.	15
5. Metagraywacke, light gray, with thin schistose layers	100
4. Metagraywacke, massive, gray white	20
3. Metagraywacke, dark gray, with whitish spots one-fourth to 1½ inches in diameter; consists largely of quartz, feldspars, muscovite, and biotite	75
2. Metagraywacke, alternating beds of dark slaty metagraywacke, massive white metaquartzite, gray striped and spotted metagraywacke, and slates	250
1. Metagraywacke, thin bedded, spotted, dense, greenish gray. (Intergrades with greenish schists below)	10
Total	1,515

The most distinctive member of the above sequence is the rather massive, olive gray, partly schistose metagraywacke at the top. It outcrops widely along the northwest flank of the Snowy Range. The spotted metagraywacke (bed number 3) and the smoky gray, strongly cross-bedded layers (beds numbers 6 to 8) are also unique in this region and are easily recognized. These rocks are analogous to the metaquartzites, but probably contained originally many minerals which have since recrystallized into feldspars, micas, chlorite, and pyrite as well as quartz.

The series as a whole is not very resistant to erosion, and hence it is exposed only in the ice-worn heads of the valleys, along the northwest flank of the Snowy Range. On account of the deficient strength of the beds, there has been a little minor folding within the formation, but folds even a few feet in breadth appear to be rare.

MEDICINE PEAK METAQUARTZITE

The Snowy Range owes its prominence and position to a great, massive metaquartzite formation. In general, the rocks are coarse grained and even conglomeratic and are very thick bedded. There are very few slaty layers or even partings. Two divisions of the formation may be recognized in the field and have been distinguished on the map; but, on account of the scarcity of geographic names, the writer found it impracticable to give separate names to the two members.

The lower member is a very massive, violet-gray metaquartzite about 1,700 feet thick. Certain beds are dark steel gray in color. The grains are large (one-half to 3 millimeters in diameter) and include small

pebbles as much as 15 millimeters thick. In addition to glassy quartz some layers contain pieces of red and sepia-colored jasper and crystals of bluish green cyanite. The latter are large, ragged bodies, associated with shreds of muscovite in the interstitial corners; both are metamorphic. The rock is generally cross-bedded in layers from one-half to one foot in thickness, with gently curved laminæ. Large boulders of this very distinctive violet-gray rock, blotched with green, are common on the moraines along the road from Centennial to Brooklyn Lake.

The upper member is unusually pure and uniform throughout the thickness of nearly 4,000 feet. It is generally not quite so coarse as the

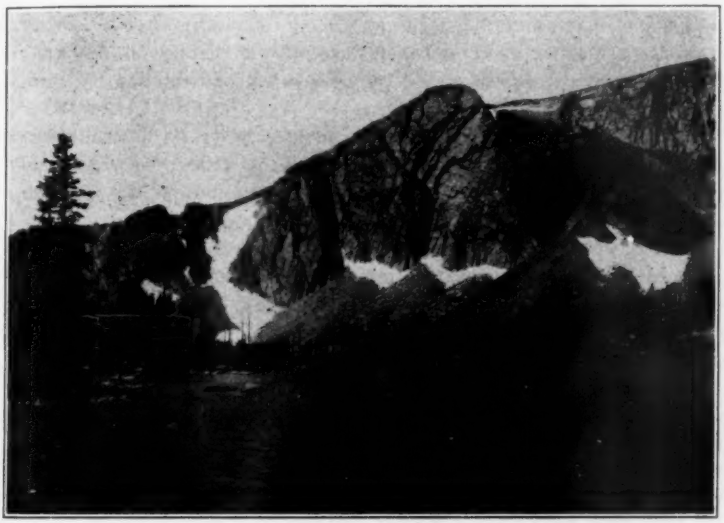

FIGURE 7.—*South End of the Medicine Bow Peak Ridge*

The view is as seen from Lake Marie. The Medicine Peak metaquartzite is well shown in the center. To the right is a large diabasic dike. To the left is one of the transverse faults.

lower member. The cross-bedding in it is not conspicuous, but that may well be due to its purity and hence lack of internal contrasts. The color is largely white, but some beds are pale gray or pale green. There is one bed of a bright emerald green, about 60 feet thick, that is conspicuous in the upper third of the formation northwest of Big Telephone Lake, and boulders of it are common in the glacial drift to the southeast. The microscope shows that this bright green color is due to the presence of a micaceous mineral, which is probably fuchsite—the chrome-bearing variety of muscovite.

In the lower part of the upper member there are some violet-gray beds that resemble those of the lower member. In addition, it is common to find the quartzite stained various shades of brown in the immediate vicinity of some of the larger basic dikes that intersect the formation.

There is but little variation in this extraordinarily thick formation. Just below the top there is a zone of conglomerate about 100 feet thick, in which well-sized and uniformly rounded pebbles of quartz, with a few of red and purple jasper, one-fourth to one-half inch in diameter, are arranged in beds 2 to 12 inches thick and generally seven to eight in number. Some of these are purple and even steel gray, owing to the presence of crystalline magnetite and hematite in the matrix. Because they are completely recrystallized, the outlines of the pebbles are ill defined. Other thin beds of fine conglomerate occur lower in the formation, but they are rare.

In the lower 500 feet of the white member, there is a local zone of drab to blackish slaty metaquartzite, alternating with fine-grained, white metaquartzite, that makes a conspicuous striped outcrop. In some parts of the section there are also thin schistose partings.

Like the violet-gray lower member, the white metaquartzite contains more or less blue-green cyanite in scattered crystals. Near Lost Lake large prisms (1 to 2 inches) of the same mineral were found inclosed in quartz veins that intersect the strata.

At the top the formation intergrades with the Lookout schist, through thin-bedded, fine-grained, pinkish metaquartzite, which is interbedded with chlorite-sericite schist in thin layers. This phase is clearly exposed at the base of the Snowy Range, northwest of the old Class Gold Mine, near the head of Libby Creek.

LOOKOUT SCHIST

The limits of this formation are defined by its conformable contacts with the massive metaquartzite formation above and below. The prevailing rock is a finely laminate, greenish gray, quartz-sericite-chlorite schist containing small amounts of biotite. This is interbedded with many thin layers of metaquartzite. The sequence is best exposed in the cirques at the extreme head of Libby Creek and on the southeast shore of Lookout Lake.

No complete section of this formation has been measured. In addition to the prevailing striped schist, which is itself subject to many variations, there are the interstratified beds of metaquartzite varying from an inch to two feet or more in thickness. In some zones the sandy

beds exceed the schists and in one case a solid bed of metaquartzite 15 feet thick was observed. The quartzitic beds are generally of white to pinkish color, but some of them are iron gray. No matter how thin the layers, they generally show well-defined, regular cross-bedding at rather low angles. North of Sugarloaf Peak a 5-inch bed of lavender-gray metadolomite was found in the schist. Again, northwest of Big Telephone Lake, the formation contains several thin metadolomite beds and also one of chlorite schist crowded with magnetite octahedra.

In some respects the Lookout schist resembles the Headquarters formation, but it is much less chloritic, has no biotite spots, and entirely lacks the conglomeratic deposits. If closely examined, the two formations are readily distinguished in the field.

On account of its weakness and its position between the two massive quartzitic formations, the Lookout schist has been rather strongly mashed, as is evidenced by the crenulation of individual laminæ in many places. North of Sugarloaf Peak and near Class Mine, there are also bodies of conglomerate-like schist which the writer considers to be autoclastic—made by the shearing, breakage, and rolling out of thin beds of brittle metaquartzite inclosed in the soft, crumpled schist. It is probable that such deformation accounts in part for the notable variations in thickness of the formation from point to point. The normal thickness is estimated to be about 1,200 feet. Near Class Lakes this is much increased, probably by flowage and reduplicative folding. On the other hand, the formation is much thinner northeast of Class Lakes, and the fact seems to be best explained by the shearing out of part of the formation along a fault.

SUGARLOAF METAQUARTZITE

The prevailing rock is a dense, fine-grained, vitreous metaquartzite of extreme purity and dull white color. Some parts of the formation are characterized by a distinctly bluish color that is quite unlike that of any other terrane in the district. Another common color is brownish white; but the more local dark brown, red, purple, and gray hues are found chiefly in the vicinity of basic igneous intrusions and are believed to be local stains.

Near the top there are a few thin beds of fine conglomerate consisting entirely of well-worn quartz pebbles in a matrix partly cemented with crystalline hematite. The formation seems to be devoid of beds or even partings of slaty material.

On account of its purity, the rock seldom reveals its internal structure, but where observed the cross-bedding is very regular and of rather large

amplitude. Some of the bedding planes show well preserved ripple-marks of the long, parallel, even-crested type. The rock has been fractured in three or more systems of joints three to six feet apart. These are so clean-cut that joint-blocks of the metaquartzite remind one of sawed and polished masonry.

Since the top of the formation has not been found actually exposed, its relation to the overlying Nash marble series is not known. At the base, however, the metaquartzite, as exposed on the northeast side of Sugarloaf Peak and also on the inlet to Brooklyn Lake, clearly intergrades with the subjacent Lookout schist.

Some students of the range have mistaken this formation for a recurrence of the Medicine Peak metaquartzite, which it superficially resembles in being a massive, whitish quartzite. On close examination, however, it appears that the two formations are quite distinct.

The Sugarloaf terrane may be distinguished from all the other quartzites in the range by its extreme purity, fineness of grain, and lack of interbedded argillaceous deposits. Isolated pieces of it—abundant in the glacial moraines—may be recognized by their resemblance to smooth pieces of Castile soap.

The exposed thickness of this metaquartzite varies from a thin wedge to 1,900 feet. Since thickening by flowage or reduplicative folding is hardly to be expected in so brittle and massive a formation, it seems probable that the maximum thickness is the original thickness. This is found in the vicinity of Lookout Lake and again near the head of Rock Creek. In the intervening space the Sugarloaf formation is faulted out, but it reappears here and there in the form of small but very typical wedges, closely associated and for the most part conformable with the Lookout schist on the north. In most places the structural relationships were not ascertained, but it is reasonably certain that faulting is the dominant cause of the discontinuity of these outcrops.

NASH MARBLE SERIES

The prevailing rocks of this thick and varied formation are dolomitic marble and chloritic schist, with intermediate types, and also some thin beds of jasper,[18] black slate, and perhaps pyroclastic rocks. The basal member is largely metargillite and slate, with but little calcareous matter. The bottom of the formation is contrasted with the massive Sugarloaf metaquartzite, but the upper limit is less well defined.

[18] The term "jasper" is used in this paper to designate recrystallized chert or flint, now composed of a granular aggregate of quartz crystals, without chalcedony or opal. Impurities may give it various colors.

A nearly complete, although partly concealed, section of the formation, lacking only the basal member, is tabulated below. This was measured, by the use of plane-table and stadia alidade, northwestward from the bridge on the west branch of Nash Fork, which is the outlet of Telephone Lakes. In estimating the thicknesses, allowance has been made for several large basic dikes and a few small isoclinal folds that were observed.

	Feet
15. Marble, gray, dolomitic, with laminæ of gray jasper and black and gray slate. Some of the dolomite beds weather to an olive-buff color and contain small concentric algal (?) domes	145
14. (Concealed.) Probably slates	165
13. Marble, massive gray to drab, with laminæ of gray jasper and some beds of black siliceous slate. This is the zone of larger algal (?) domes	195
12. (Concealed)	50
11. Marble, gray, dolomitic, weathering buff and brown and alternating with chloritic schist; contains some thin beds of black and olive-yellow crystalline chert	30
10. (Concealed, except for a few beds of gray marble)	335
9. Marble, buff ferruginous dolomite that weathers to a characteristic striped brown, buff and violet-gray earthy surface; laminæ 1 to 5 millimeters thick	75
8. (Concealed)	85
7. Marble, dense gray, impure rock, with more or less striped steel-gray surface	60
6. (Concealed.) Largely chloritic schist and schistose dolomite	290
5. Marble, striped rock like number 10	30
4. Marble, flesh to rose color, weathering buff, brown, and white	55
3. Schist and marble, thin-bedded, schistose metadolomite and chlorite-schist	125
2. Marble, white to rose-colored, weathering buff, with thin layers of brown jasper; zone of largest algal (?) growths	80
1. (Concealed.) Partly schist, with thin beds of gray marble	250
Total	1,970

The lowest member of the formation, which is believed to be faulted out at Telephone Lakes, is best exposed northwest of Brooklyn Lake (see page 651.)

On account of the relative weakness of some members of the formation, continuous sections are not to be found. However, a nearly continuous partial section (equivalent approximately to beds numbers 2 to 5 in the above section) is exposed in a shallow ravine about two-thirds of a mile southwest of Telephone Lake. In condensed form, this is given below:

	Feet
8. Marble, alternate beds of striped brown-weathering marble, massive cream-white buff and rose marble, and thin laminæ of gray jasper..	180
7. Marble, massive, white to gray, weathering buff and tawny, interbedded with layers of striped marble, as above.....	100
6. Marble, like number 8, but with very little jasper. Most of the marble beds are rose colored, with tawny exteriors.....	280
5. Marble, alternate beds of platy schistose marble and greenish gray chlorite schist.....	45
4. Marble, very massive gray quartzose marble, with buff exteriors, partly ribbed with jasper and partly containing scattered jasper lenses.....	90
3. Marble, interbedded, striped brown, gray, and pink marble and impure steel-colored marble, with a few beds of waxy banded gray and olive-yellow jasper.....	75
2. Marble, very massive to slaty, whitish quartzose marble, weathering to a light brown; closely ribbed and pitted on the weathered surface. These beds contain huge algal (?) domes of 5 to 10 feet radius.....	95
1. Marble, interbedded buff and gray marble and banded gray mica schist.	40
Total	905

These sections reveal the fact that the Nash marble series formerly consisted of alternating shales, dolomites, and perhaps limestones, with considerable chert and a basal silt and graywacke member. The rocks are now entirely recrystallized, but the change has not greatly obscured their original structure, lamination, and relations. No doubt the weaker members have suffered thinning and thickening, and even reduplication in small folds, but the more massive dolomitic marbles have not been much distorted.

The marble layers show nearly all the characteristics and variations commonly seen in Paleozoic dolomites and limestones. There is much range in color, in purity, and in thickness of beds. Some layers are calcarenites and others calcirudites.[19] Cross-bedding, current-marks, and variations of texture can be clearly seen in some of these layers.

One of the most interesting features of the more massive marbles is a type of contemporaneous structure which is probably organic in origin. In certain strata, chiefly of the upper and middle zones of the series, there are many concentric domes, or globes, crowded together and all resting on a common base. These domes range in size from an inch or more to as much as 10 feet in radius. Their gross anatomy is generally emphasized by alternations of more dolomitic and more siliceous bands, of which the latter weather out in relief. A close study of these features strongly suggests that they have been built by colonial organisms.

[19] "Calcarenite," indurated calcareous sand; "calcirudite," indurated calcareous gravel (after Grabau).

such as calcareous algæ. It is not to be expected that the organic microstructures can be found preserved, since the rock is entirely recrystallized. However, the forms and structures of the bodies, their occurrence always in certain massive layers, which show no other evidence of internal deformation, and their emplacement upon a bedding plane combine to show they are not due to structural deformation. In the opinion of Dr. Walcott, of the Smithsonian Institution, to whom photographs of these features have been referred, they are of algal origin and probably referable to the genus *Collenia*.[20]

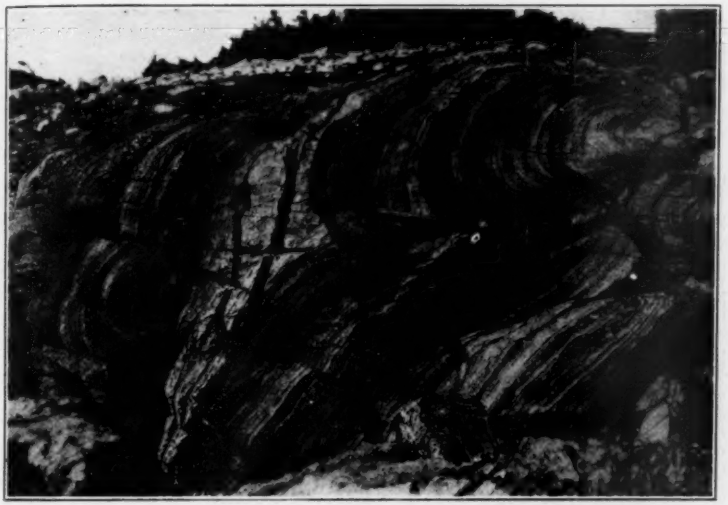

FIGURE 8.—*Large dome-shaped structures*

They are believed to be algal colonies in the dolomitic marble of the Nash series. The locality is south of West Telephone Lake.

One of the most distinctive phases of the series is a banded gray to blackish dolomite, the weathered surface of which is buff to dark brown or even sepia color. In the field this was conveniently called "striped rock." The microscope shows that it is an impure recrystallized dolomite, clouded with graphitic matter and containing considerable amounts of siderite and probably manganese carbonate. The thin, even laminæ, 1 to 10 millimeters in thickness, strongly suggest seasonal banding. If

[20] Charles D. Walcott: Pre-Cambrian Algonkian algal flora. Smithsonian Misc. Coll., vol. 64, no. 2, 1914.

they are actually annual layers, it would be quite possible to count the time represented by these particular members of the series.

The more slaty components of the series are chiefly chloritic. There is every variation, from black clay slate through green chlorite schist and chloritic, thin-bedded marbles, to the more massive marble strata. In one of the gray clay-slate layers polygonal cracks were found filled with a darker, more gritty slate. These appeared to have all the essential characteristics of ordinary mud-cracks.

The basal member of the marble series consists of steel-gray or blue-gray, impure metargillites and phyllites. These are best exposed north-

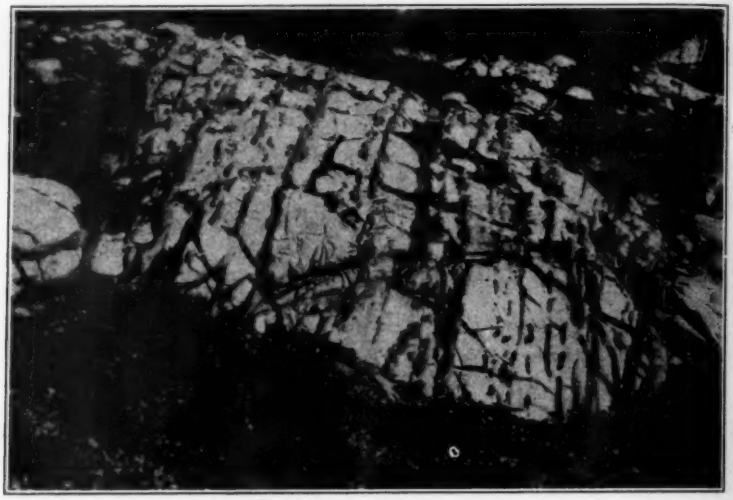

FIGURE 9.—*Pure white Marble, with Beds, Lenses, and Nodules of Jasper*

This is a typical member of the Nash marble series and is situated south of West Telephone Lake.

west of Brooklyn Lake. They are generally very fine grained and contain sufficient siliceous matter to make them relatively hard. The microscope shows that they consist of quartz, sericite, and feldspar, sprinkled with crystals of hematite or magnetite, a little pyrite, and scattered flakes of biotite. The weathered surfaces are relatively smooth and are not stained with iron oxides. Massive and thin-bedded layers alternate with sericitic and even chloritic phyllites. Among them may be found a few thin beds of white and gray marble that weather to the usual buff color. Some of the metargillites are more or less calcareous and even contain

nodules of gray jasper. This lower member of the series is so distinctive that it will doubtless be possible to map it as a separate formation. The lowermost 60 feet, adjacent to the metaquartzite, were not found exposed.

As might be expected, most of the movement in the mass has been taken up in the schistose layers, and hence they are much more deformed than the massive beds of marble. Many of the laminæ are minutely crenulated and others are closely sheared. In a few places the writer found small closed folds, of which the largest observed was 30 feet in breadth. In general, however, there is in this entire series surprisingly little evidence of reduplication by folding. The various members, although representing many variations of a few themes, are so distinctive that by close scrutiny they can be clearly recognized in the field. In view of this fact, it is noteworthy that the more distinctive layers were not found repeated by folding, although the exposures in many places are both excellent and comprehensive.

ANDERSON PHYLLITE[21]

This formation consists largely of recrystallized dark-gray and black slaty rocks, with some calcareous and a few sandy strata. It appears to intergrade with the inclosing formations both above and below. The best outcrops were found along Nash Fork, Libby Creek, and the high divide between the latter and French Creek. The various beds are so weak that only intermittent outcrops are available, and therefore no continuous section could be measured. The general sequence appeared to be somewhat as follows:

	Feet
5. Marble, schistose series of chloritic and talcose marble of buff and dove colors, with crumpled chloritic schists, much speckled with ocherous cubes derived from pyrite	500
4. Phyllite, dark olive to smoky-gray, finely laminated, chloritic biotite phyllite, grading down into dark-gray to blackish phyllite, more coarsely banded and containing many 6–12-inch beds of black micaceous marble	200
3. Phyllite, coarser gray, siliceous phyllite, with metagraywacke flags that weather to a purplish brown color	500
2. Phyllite, olive to sooty-gray, crenulated phyllite, with thin beds of tawny-weathering, schistose marble	300
1. Coal-black to light-gray, graphitic and sericitic phyllite, with thin beds of schistose dolomite. Outcrops of the darkest slates are generally stained reddish purple and contain rusty cubes derived from pyrite	100
Total	1,600

[21] Named for the old Anderson mining prospect, on Libby Creek, near the contact between this formation and the underlying Nash marble series.

On account of its weakness, it is probable that there has been much isoclinal folding on a minute scale, and in general that the beds have been rolled out and mashed, so that estimates of the original thickness are liable to serious error. Even hand specimens show tiny crenulations in many of the beds.

In general the most typical members of the formation are finely banded phyllites of sooty-gray colors. The laminæ are one-half to 5 millimeters thick. The rocks were probably derived from laminate clay shales and silt shales, with some calcareous shales and thin calcareous sandstones. One bed of the latter still preserves its complex current bedding of the cut-and-fill type. The colors are generally due to fine graphitic powder with some biotite and considerable pyrite. The deltaic sediments of a semitropical coastal plain are suggested.

Although the Anderson phyllite is easily distinguished from most of the more schistose formations of the region, it is likely to be confused with the French slate and with some of the argillaceous members in the Nash marble series. From the latter it can generally be distinguished, because the schistose members of the Nash series are comparatively thin and are always closely associated with white or buff marbles and beds of gray jasper. The Anderson and French slates resemble each other much more closely and would, in fact, be separated with great difficulty, except where their relations to the adjacent formations are clear. However, the French slates seem to contain no calcareous beds and do contain thin, more sandy layers. Both formations are, however, dark gray, finely banded rocks containing much pyrite.

RANGER MARBLE

Massive, light bluish gray, fine-grained marble of dolomitic composition is the most characteristic rock of the formation. Some of the beds weather to a buff color and a few to olive drab, but blue gray is more common. There is comparatively little jasper or other siliceous material and the schistose members are few and thin. A tolerably complete section, which was measured with the aid of plane-table and stadia, on the broad divide between Libby Creek and French Creek, is as follows:

	Feet
(Contact with the green schist concealed.)	
33. Massive dark-gray marble, weathering blue gray. Alternating beds, originally of calcarenite, calcilutite,[22] and probably some oolite. No jasper	60
32. (Concealed by drift)	150

[22] Indurated calcareous mud (Grabau's terminology).

	Feet
31. Marble, dark gray to black, massive but greatly jointed. Finely laminate and has concentric structures, 2 to 4 inches in diameter, supposed to be of algal origin	45
30. (Concealed)	180
29. Marble, medium to dark gray, weathering blue gray to pale buff; a few thin laminæ and lenses of gray jasper	90
28. (Concealed)	30
27. White marble, with tremolite rosettes, probably due to contact metamorphism by a dike	5
26. Marble, gray, with thin laminæ of gray jasper	19
25. Sepia-brown sericite phyllite, with minute pyrite cubes	4
24. Pale-brown marble, weathering buff, with thin beds of cream-colored jasper	12
23. White marble, with some tremolite	20
22. Massive light to dark-gray marble, of dense to sugary texture. It is cut by large white quartz veins, but is nearly devoid of jasper. Some of the beds are finely and very evenly banded	65
21. Like next above, except that there are many rough laminæ of gray to rusty-colored jasper and a few algal (?) domes 2 to 6 inches in diameter	24
20. Massive light-gray marble, weathering to smooth gray and cream-colored surfaces; contains algoid domes and sedimentary breccias, but no jasper	22
19. Schistose ferruginous marble, weathering to a bright ocher color; largely concealed	8
18. Marble, a more massive phase of the next above	27
17. (Concealed.) Probably schistose	9
16. Marble, massive light gray, weathering bluish; contains one 2-foot bed and a few thin laminæ of massive iron-gray jasper	60
15. Marble, light gray, banded, weathering blue gray; surfaces smooth	25
14. (Concealed)	40
13. Marble, massive, blue gray, minutely fractured	25
12. (Concealed)	90
11. Pale-gray schistose marble, with chlorite on shearing planes; weathers to a tawny and even olive-drab color	30
10. Massive pale-gray to whitish marble, with a few 2–10-inch beds of grayish brown jasper	45
9. (Largely concealed.) A few outcrops of dark-gray banded marble	75
8. Marble, sooty gray, finely banded and weathering bluish; surface much jointed	27
7. Marble, light gray, banded, weathering to a smooth blue-gray surface. The rock is very massive and contains a few small whitish disks of jasper	50
6. Very massive, pearl gray to whitish marble, thickly studded with jasper disks about one-half inch in diameter, and of random orientation	12
5. Banded gray marble, with very little quartz	56
4. (Concealed)	160

	Feet
3. Very massive, dark to medium gray marble, which weathers bluish; some layers are banded. Many brown and white quartz veins, but no jasper lenses	195
2. Schistose buff and dove-colored marble, largely concealed	45
1. Thin-bedded schistose gray and pinkish marble, with chloritic partings, generally weathering to buff, tawny, and rusty colors; poorly exposed. (Apparently intergrades with the Anderson schist below)	125
Total	2,395

Although the rocks in the above section are entirely recrystallized, they strongly suggest certain Paleozoic dolomites of the Appalachian Mountains and of Nevada. The original sedimentary structures are still visible, and it seems probable that even fossils remain, in the form of algal domes.

The Ranger marble reappears in poorer exposures at various points northeastward to the Brooklyn Ranger Station, from which the formation name has been taken, and perhaps as far as Mill Peak. In spite of the fact that the Nash series consists largely of marble, it is not difficult to distinguish these two formations in the field, as their stratigraphic details are dissimilar. On the whole, the Ranger marble contains less jasper and fewer schistose beds. The distinctive striped brown metadolomites and the basal metargillites of the Nash series are entirely absent. Most of the Ranger marble contains so little iron that its weathered surfaces do not assume the buff or brown colors of the older formation. The only coloring matter seems to be a small amount of carbon, sufficient to produce various shades of gray. The algoid domes of the Ranger marble are all small and are inconspicuous features of the formation, whereas in the Nash series they are more common and reach much larger size.

TOWNER GREENSTONE[22]

This is one of the most obscure and least understood formations in the district. It consists of massive to schistose chloritic and hornblendic rocks, the origin of which is not altogether certain and the detailed sequence of which has not been worked out.

The more massive phase of the greenstone is fine-grained and often ophitic. It has the aspect of a gneissoid basaltic flow-rock, now largely uralitized. Another phase has ill-defined lens-shaped structures, suggesting that they may have been water-laid tuffs.

In general the characteristics of this formation suggest that it con-

[22] Named after Towner Lake, one of the sources of Nash Creek.

sists of a series of basic pyroclastics and flows, now recrystallized and considerably mashed. The weathered surfaces resemble those of the Hemlock volcanics (pre-Cambrian) of northern Michigan.

The best exposures of the Towner greenstone are to be found along the new road, between Brooklyn Lodge and Towner Lake. The formation seems to vary in thickness from about 600 to more than 1,200 feet. This may be due in large part to uneven compression of a weak terrane. Its upper and lower limits have not yet been observed, as the contacts are apparently always covered with glacial drift, but the uniformity of the outcrop suggests conformable relations.

FRENCH SLATE[24]

Exposures of this formation are so scattered that it was not found practicable to measure a detailed section. However, the many incomplete outcrops show very clearly that it consists largely of dark-brown to blackish gray phyllites, with thin beds of quartzitic rocks and some laminæ rich in magnetite and hematite. Pyrite cubes, generally altered to limonite, are relatively abundant. The formation is a rather monotonous sequence of slaty rocks in which it is difficult to single out any distinctive members. Furthermore, it is inherently probable that in so weak a formation there may be isoclinal folds of considerable magnitude that would invert part of the strata. In a general way, however, certain zones of the formation appeared to be recognizable, and these are tentatively outlined below.

About twenty feet above the Towner greenstone the prevailing rock is a sooty-gray phyllite, slightly banded and faintly tinged with green. This passes up into more distinctly laminate dark, sericitic phyllites, which are minutely crumpled. These rocks are well exposed west of Brooklyn Lodge.

About 350 feet above the base there are black graphitic slates with thin layers (3 to 10 inches thick) that are hard and rich in hematite. There are also a few thin layers of brownish gray schistose quartzite in which biotite and muscovite have developed in small quantities.

From about 600 to 1,000 feet above the base the prevailing rocks are obscurely banded sericite phyllites of brownish gray color, some beds of which are speckled with biotite crystals about one millimeter in diameter. With these are purplish gray phyllites and black phyllites which weather to a rusty-brown color. From about 1,350 to 1,700 feet above the base, there are silky gray phyllites, interbedded with coarser sericite schist and

[24] Name derived from French Creek, the south fork of which runs along the outcrop of this formation for several miles.

thin beds of actinolitic schist and hornblende-magnetite rock. Within 100 to 200 feet of the top of the formation, along Nash Fork, the prevailing rock is dark-gray phyllite or silvery schist, consisting of biotite, muscovite, and a little chlorite, in addition to the usual quartz and alkali feldspars. With these are associated beds of massive gneissoid greenstone 10 or 15 feet thick. The latter may have been thin basaltic flows or sills, now metamorphosed.

The average thickness of the formation appears to be about 2,000 feet, assuming that there are no considerable folds within it. The basal contact was not found, although the covered zone was in one place only 20 feet wide. The upper limit is uncertain. It has not yet been observed. Reference has already been made to two theories[25] regarding the relation between this formation and the adjacent gneissic complex. If the gneisses are part of the sedimentary sequence, injected and granitized by solutions from a neighboring batholith, then a gradation rather than a sharp contact should be expected. On the other hand, if the gneisses are decidedly older and are faulted against the slates, then there would be no such intergradation. As exposures are not continuous and are not so good as they are in the higher parts of the range, the writer did not reach a conclusion on this point. To do so will require a more thorough and critical examination of the whole contact belt.

In support of the opinion that the gneissic complex is merely the intensely metamorphosed part of the slates and other sedimentary formations, it has been urged: (*a*) That no sharp contact, such as a fault, has ever been observed between the two masses; (*b*) that the gneissic complex contains some isolated bodies of marble which are clearly of sedimentary origin; and (*c*) that the minute injection of magmatic solutions along cleavage planes in the slates, with the resulting recrystallization and granitization of the latter, would have produced such a rock as the striped gneiss. However, it seems to the writer significant that, although pegmatite dikes of two or three distinct ages are exceedingly abundant in the gneissic complex only a few hundred feet from the contact, they are rare in the French slates and underlying formations and are of one generation only. Also, the few small pegmatite veins that have been observed in the French slate can be matched in the Lookout schist and quartzite formations two miles farther to the northwest, as well as on the west side of the range. Although the type of rock that makes up the French formation is decidedly susceptible to contact metamorphism, these slaty rocks do not appear to be distinctly more coarsely crystalline than those of the central part of the range, nor do they seem to contain

[25] Page 625.

typical contact minerals, such as andalusite, tourmaline, topaz, cordierite, garnet, or staurolite. Thirdly, the contact between the gneisses and the French slates is substantially parallel to the strike. If it were an igneous contact, it would probably transect the sedimentary formations without particular regard to their stratification, for such is the usual habit of batholiths.

ACIDIC INTRUSIVES

Excepting the granitic parts of the gneissic complex, which have already been noted, there are but few acidic intrusions in the Medicine Bow Mountains. Those which have been observed, both north and south of the gap in the Snowy Range and near the head of Brush Creek, may be regarded as small stocks. They are indicated on the map, but have not been closely studied.

The best exposed of these bodies is the stock in the cirque about one mile due east of Medicine Bow Peak. The intrusive itself is a slightly gneissoid pink quartz-monzonite consisting of orthoclase, soda-lime feldspars, quartz, and biotite. On the west side there is a broad contact breccia of fragments of gray quartzite in a matrix of the pink alaskitic intrusive. Smaller bodies of similar rock were found north of the gap.

The two small intrusions of flesh-colored granitoid rock near the headwaters of Brush Creek, on the west side of the range, are not as well exposed. It is assumed that these have been intruded into the green schists, although the contacts were not observed.

In addition to the stocks, thin pegmatite dikes and quartz vein-dikes are widely distributed through the district, although nowhere are they abundant as in the gneissic area. Most of these dikes are less than six inches wide and many of them less than one inch. The pegmatites consist chiefly of dull-gray quartz, with white or gray feldspars. A much larger number of veins consist entirely of quartz. In the lower part of the French slate, veinlets of two distinct ages were found. The older consist of pyrite and quartz intruded along the cleavage and afterward crumpled. The younger generation is represented by small pure quartz stringers which have not been deformed. Near Lost Lake some of the larger quartz veins contain crystals of blue-green cyanite one to three inches in length. This occurrence suggests that the country rock, which contains much disseminated cyanite, was the ultimate source of the coarse vein material.

BASIC INTRUSIVES

In contrast to the granitic intrusions, those of dark-green basic rocks are much more prominent in the Medicine Bow district. Dikes twenty

to hundreds of feet thick are relatively common throughout the region and even become conspicuous in the scenery where they are cleanly exposed, in the southeast front of the Snowy Range (figure 7). The commonest type of rock may be classed as an ordinary diabase, somewhat altered to chlorite, saussurite, etcetera, but neither gneissoid nor schistose. Such types are obviously younger than the recrystallized sedimentary formations. In some the texture is clearly ophitic and in others granitoid. Some are coarse enough to be better classed as gabbros. In some cases they are now distinctly schistose or gneissoid, and from this it is suspected that the basic dikes are not all of the same age. One of them, near Class Lakes, contains a good deal of black tourmaline in sheafs and rosettes. Some others contain unusual amounts of magnetite.

The largest dike observed was in the slope of Windy Hill. It appears to be more than a thousand feet thick. The rock is a rather coarse, unaltered olivine gabbro that reveals no microscopic evidence of strain.

In general the basic dikes have not exerted much influence on the rocks which they invaded. The more massive quartzites are commonly stained a brownish color a few inches or even a few feet from the contact. Silicates (probably tremolite) have been developed locally in the dolomitic marbles on the southeast side of the range, where intersected by diabasic dikes.

If all the dikes of the district should be mapped, they would probably be found to be arranged in two or three rather well-defined systems intersecting at large angles. Many of the dikes follow known faults; others occupy joints. Definite sills appear to be rare.

YOUNGER FORMATIONS

Sedimentary formations of Carboniferous and Mesozoic age are exposed around the flanks of the Medicine Bow dome, but they do not come within the scope of this paper. There are also some interesting deposits of conglomerate, probably of Tertiary age, along the upper course of Nash Fork, well within the pre-Cambrian area. They are firmly cemented with calcareous tufa and rest upon the planed surface of the ancient rocks. There is Quaternary glacial drift of two and perhaps three ages upon the Medicine Bow Plateau, but they also will not be discussed in this paper.

Geologic Structure

In general the sedimentary beds are nearly vertical or steeply inclined to the southeast. The dips are gentler on the northwest side, and in the

FIGURE 10.—*Geologic Cross-section of the Snowy Range District, through Brooklyn Lake*

Formations the same as in figure 11.

FIGURE 11.—*Geologic Cross-section of the District*

The locality is a little south of Medicine Bow Peak. The formations shown are:

(A) Deep Lake metaquartzite.
(B) Headquarters schist.
(C) Heart Lake metaquartzite.
(D) Medicine Peak metaquartzite.
(E) Lookout schist.
(F) Sugarloaf metaquartzite.
(G) Nash marble series.
(H) Anderson phyllite.
(I) Ranger marble.
(J) Towner greenstone.
(K) French slate.
(L) Gneissic complex.

region west of Gold Hill there are local northwesterly dips, indicating the presence of an anticline. The observations made by Van Hise[26] in the course of his hasty trip across the range suggested to him that a large syncline lay to the east of the Snowy Range and a broad anticline several miles to the northwest. The latter fold is probably the one near Gold Hill, but our detailed examination of the eastern part of the district has shown that there is no repetition of beds on a large scale and therefore no large syncline.

In beds devoid of fossils, of unknown stratigraphy and in vertical attitude, the true order of deposition is not always easily determined. In this instance it was found necessary to search very carefully for original sedimentary structures, and to weigh their evidence separately from that of the secondary structures, such as cleavage and drag-folds, that are due to deformation. In this instance the former consisted of clearly preserved ripple-marks in some of the metaquartzite formations, cross-bedding and variation of texture in sandy and dolomitic members, and the dome-shaped growths, supposedly of algal origin, in the marbles. A close study of the ripple-marks, cross-bedding, and change of grain showed that the top of the stratum in each case faced southeastward. Likewise the algoid domes are all convex toward the southeast, are attached to flat bases which have every resemblance to a contemporaneous sea-floor, and are surrounded with detrital dolomite (or calcarenite) resembling reef debris. All of these criteria, therefore, indicate that the southeast sides of the various formations were originally their tops, and that the sequence as it stands is not overturned.

In so thick a sequence one might reasonably expect to find unconformities, but of their presence there is little direct evidence. There is ample proof, already cited, that the relation between some of the formations is conformable, but in other cases the necessary contacts have not been found. Even in the latter instances, however, there are no conspicuous basal conglomerates, discordances of bedding, or suggestive overlaps to indicate the presence of unconformities. If any exist, therefore, it is probable that they are obscure and in the nature of disconformities.

Except for the Gold Hill anticline already mentioned, we found no indication of the presence of large folds in the sedimentary formations. Small folds are abundant, but are confined to the weaker members of the sequence, such as the slates, phyllites, schists, and thin-bedded marbles. They were not found in the massive metaquartzites or thick marble layers. This distribution is presumed to be due to the fact that differential

[26] See page 617, footnote 3.

movement is generally concentrated in the weakest members of a folded series. In a sense, they lubricate the more massive terranes that transmit the thrusts. On the whole, however, it is remarkable that in the Medicine Bow district these softer, yielding formations do not show greater evidence of great shearing, with the development of complex minor folds on a grand scale. No folds of this kind more than 30 to 50 feet across were observed, and the great majority of them are to be measured in inches or even millimeters. The weakest of the phyllites are in many places finely crenulated.

The faults observed in the district are of two general kinds. The best known are the transverse normal faults, five of which are represented on the map. Most of these have been actually observed and are found to be clean, nearly vertical fractures, on which the movement was largely vertical. In some cases they are marked by narrow zones of breccia, now cemented by limonite. Such a breccia is clearly exposed at the southwest end of the Medicine Bow ridge, west of Lake Marie, and there is another northeast of Brooklyn Lake. Since they offset the outcrops of the steeply inclined formations many hundreds of feet, it is probable that these faults have displacements amounting to thousands of feet.

A strike-fault, which may be an overthrust, is indicated by outcrop relations from Class Lakes northeast toward the south fork of Rock Creek. This fault has apparently sheared off the various members of the Medicine Peak quartzite, one after the other, until only the lower schistose members are left. It is this distribution of outcrops that determined the northeast end of the Snowy Range, the existence of which depends on the presence of the thick, massive, and exceedingly resistant metaquartzites. At no point has this fault been actually observed. The straightness of its trace suggests that it has a steep dip. The outcrop relations might be accounted for by an unconformity at the base of the Lookout schist, but this hypothesis is rendered improbable by the finding of a plainly conformable gradation between the Medicine Peak metaquartzite and the Lookout schist north of Sugarloaf Peak. From Class Lakes southwestward the full thickness of Lookout schist appears to be present and nothing suggesting a fault was found. It may be that the fault dies out near Class Lakes, but it is also possible that it veers slightly to the south and continues above the Sugarloaf metaquartzite. The absence of most of the lower members of the Nash dolomite series southwest of Libby Creek suggests that they may have been thus faulted out.

As already mentioned on page 625, there may be a great fault between the French slates and the gneissic complex to the southeast. If

the slates are the youngest member of the series and the gneiss the oldest, their juxtaposition would hardly be possible without a great displacement along a strike-fault. There is, however, no direct observational evidence of its existence.

The intrusive igneous structures of the range consist of a few small stocks, mostly of pink granitoid rocks, many large dikes of diabasic and gabbroid rocks, as well as vein-dikes of quartz and pegmatite. Elsewhere in the Medicine Bow region there are probably large batholiths of granite. Such a mass is reported southwest of Albany Post Office, and Sheep Mountain, to the east, consists largely of granite. It may well be that the small stocks in the area covered by our survey are merely cupolas on batholiths concealed at greater depth. The intense recrystallization of all the Medicine Bow rocks may well be an effect of such a buried batholith.

It is a fact well known to structural geologists that secondary deformational structures, such as drag-folds and cleavage in the weaker members of a stratified series, are controlled by the differential movements between the more massive and resistant layers, and that these directions of movement are definitely related to the axes and limbs of folds or to overthrust blocks. In the Medicine Bow region there is a puzzling state of affairs for which no adequate explanation has been offered: The testimony of drag-folds and slate cleavage regarding the top and bottom of the sequence is generally opposed to the more reliable evidence of original sedimentary structures, such as algal domes, ripple-marks, cross-bedding, and change of grain. A harmonizing of this conflict of evidence must await further study; but meanwhile it is important to understand that the secondary structures are not to be relied on in this district, except to show the relative directions of movement in different parts of the mass.

In general the deformation of these pre-Cambrian rocks appears to have taken place nearly all at one time, after the deposition of the great sedimentary formations. The compression must have been exerted under such conditions of depth and temperature that flowage was induced not only in the schists, but also slightly in most of the rather resistant rocks, and to a perceptable degree even in the most massive metaquartzites. The cross-faults and probably the strike-faults are presumed to have been made at a later time, because the conditions of load and temperature that would permit the formation of fracture systems cutting all the formations indiscriminately would probably be less severe than those under which the flowage structures were made. Furthermore, the rocks brecciated along the faults were already metamorphic. At this time or later

some, if not most, of the basic intrusions in the sedimentary formation were introduced, since many of them follow the cross-faults.

The major folding is certainly pre-Carboniferous and almost as certainly pre-Cambrian. Nowhere in the eastern part of the Rocky Mountain system are any of the rocks of Paleozoic age so intensely deformed and recrystallized. Even such younger pre-Cambrian formations as the Uinta quartzite of Utah and the Belt terrane of Montana are much less disturbed and metamorphosed. It is therefore believed that the deformation occurred in an epoch before the latter part of the Algonkian period (Proterozoic era) rather than at its close. Since the cross-faults are followed by basic dikes, which are characteristic of the pre-Cambrian formations of the Rocky Mountains, but are entirely unlike those which locally intersect the Paleozoic formations, it is believed that most of the faulting is likewise pre-Cambrian. On the other hand, it is known that there has been some post-Cretaceous faulting and gentle folding, the results of which are easily observed in the Mesozoic formations. The effects of this later disturbance upon the pre-Cambrian rocks are not important enough to be separately recognized in the vicinity of the Snowy Range.

Metamorphism

Practically all of the rocks of the Medicine Bow Plateau have recrystallized into either massive or schistose metamorphic rocks. The change was a regional one, the effects of which are rather uniform from place to place, except as the original composition of the rock varied.

Although the gneissic series was not thoroughly examined by the writer, it is known to contain rocks which were originally sedimentary deposits, such as dolomite and shales, and others which were probably basic volcanic rocks. These have been completely recrystallized and also injected along cleavage, bedding, and joints by pegmatite-forming solutions. The latter have permeated the rocks so completely as to convert them into striped gneisses, and have also formed broad pegmatite dikes intersecting them in various directions in a most complicated manner (see figure 4). Some of the pegmatite and quartz dikes have been intensively crumpled since they were made, but the others, intersecting them and presumably of more recent age, have not been deformed. Associated with these metamorphosed, apparently sedimentary rocks, there are granitoid augen-gneisses that are diagnosed as older porphyritic granites, much altered under shearing stresses.

These indications that the gneissic series has suffered two or more periods of intense metamorphism deserve consideration with reference

to the question of the relative ages of the gneissic complex and the sedimentary formations of the Snowy Range. At present this question must be left open, to be decided by more detailed and critical studies in the future.

In the sedimentary sequence of formations, each rock type has produced its appropriate metamorphic equivalent, depending on the chemical composition of the original material. Thus, pure dolomite became white marble, and less pure varieties are streaked with chlorite, sericite, and quartz. The black shales became graphitic biotite phyllites with large cubes of pyrite. The tillites and associated glacial silt rocks became biotitic, massive, and schistose types, complex mineralogically.

Very few of these more susceptible rocks retained any of their original crystals, although they appear to contain practically all of their primary chemical constituents, now rearranged in new crystals of the same or chemically related minerals. In the thick beds of massive dolomite, recrystallization, although complete, has been so gentle as to leave many of the original structures and textures distinct. For this reason one may easily recognize, on good outcrops, variations of the original calcareous muds and sands, cross-bedding of the latter, contemporaneous erosion features, and intra-formational conglomerates. Even such fossils as existed have been tolerably well preserved. Shearing has been limited to the weaker members of the series.

The quartzites, although more resistant to metamorphic processes, have been completely recrystallized like the rest. The original grains and pebbles are seen but vaguely in thin sections, and there is no distinct cement. The crystals show a granitoid texture in which the grains fit together tightly along angular sutures; nor are the rounded grains merely completed by the enlargement of the original crystal, as described by Van Hise.[27] The impurities, if any, appear in the form of scales of chlorite and sericite, with crystals of hematite, magnetite, and even cyanite. That there has been little or no movement in the body of many of these massive quartzites is shown by the perfection with which such structures as ripple-marks and cross-bedding are still preserved without perceptible distortion. On the other hand, some are rather minutely granulated to such a degree that the original grains are almost obliterated and a gneissic structure appears.

Evidence of contact metamorphism, even in the vicinity of large basic dikes and small granitoid stocks, is slight. Local discolorations are often the only visible effect. On the margins of certain dikes and peg-

[27] R. D. Irving and C. R. Van Hise: On secondary enlargement of mineral fragments. U. S. Geol. Surv. Bull. 8, 1884.

matite veins in the Ranger marble and in a few other places, the marble has been altered to a white rock in which such minerals as tremolite form radiating aggregates definitely related to the igneous contact; but such zones are rarely more than a few inches thick. Nowhere in the district did we find any contact aureoles containing garnet, diopside, topaz, cassiterite, or other minerals characteristic of contact metamorphism.

In general the changes which these rocks have suffered are such as to suggest that they were due to intimate internal changes in the rocks, under the influence of rather high temperatures and a heavy load, but with differential motion only in the less massive and weaker rocks. But little evidence was found to indicate that there has been more than one episode of metamorphism since the great sedimentary formations were made. This is believed to have followed or accompanied the major folding of the strata and to have preceded the transverse faulting.

PALEOGEOGRAPHY

To interpret successfully the varying conditions under which these pre-Cambrian strata were deposited would require a more complete understanding of the metamorphism of such deposits and of the principles of sedimentation in general than is yet available. One can not say with confidence what kind of deposit a greenish chloritic schist was derived from, and even if that were feasible, the environment at the time of its origin would not be definitely understood. Nevertheless, although one can not give a full and satisfactory interpretation of these formations, even the present state of our understanding permits the drawing of a rough picture of the early pre-Cambrian conditions in southern Wyoming.

The source of the sediments must have been adjacent uplands, consisting partly of older metaquartzites, schists, and granitoid gneisses, for these rocks are found as pebbles in the conglomerates. Other rocks which may well have been present were perhaps destroyed by chemical decomposition in advance of erosion. That thorough decay was an important factor in preparing many of the sediments is indicated by the great purity of the sands which now form the metaquartzites and of some of the clay rocks which are now sericite schists or slates. If we may infer from present conditions, such decay indicates a surface so covered with vegetation as to hold the residual soil during the process of its formation.

Since the formations are many thousands of feet thick and yet bear clear evidence that most of them were deposited either in shallow water

or on continental surfaces, it is inferred that the region of deposition was gradually sinking—now beneath a shallow sea and now partly above sea-level. The suggestion is that of a geosyncline, like that of the Paleozoic Appalachian region or the later Tethys of Eurasia. At times of submergence beneath the shallow sea alternating beds of mud and dolomite were deposited. The thick, uninterrupted formations of dark striped slate suggest a delta coast with swampy lagoons and anerobic conditions that favored the formation of black sulphurous muds. The great thicknesses of pure quartzite represent sifted sand that might have been deposited and worked over on a marine shelf, like that around Cape Hatteras, on the Atlantic coast of the United States. That some of the sand was accumulated on land or on river floodplains is suggested by the presence of mud chips in some parts of the Deep Lake metaquartzite. The great thickness of the pure sand deposits is, however, difficult to account for by modern analogy.

There is a rather widespread notion that the pre-Cambian eras were characterized by great volcanic activity. In the Medicine Bow formations, however, we have indication of only two brief epochs during which volcanic ash and probably some lava-flows were ejected in southern Wyoming. These epochs were at the beginning of the deposition of the Headquarters schist and at the time of forming the Towner greenstone.

Orogenic movements within the time represented by the sedimentary formations are not indicated by the existing structures. Only gentle warpings are consistent with the absence of well-defined unconformities.

Variations of climate comparable to those of much later eras are clearly indicated. The three persistent zones of glacial deposits in the Headquarters schist suggest recurrent epochs of advance and retreat of an ice-sheet, or perhaps of a large piedmont glacier, associated with marginal lakes in which the laminated silt deposits were made. A very different climate is suggested by the thick beds of dolomite. It now seems well established that dolomites are chiefly formed in tropical waters, with abundant life and complex biochemical changes. Still another variety of climate is suggested by the thick layers of finely laminated, dark phyllites. Nowadays the formation of such deposits is favored by a moist climate of mild or cool temperature. It suggests an abundance of vegetation on the land. While it can hardly be supposed that there were forests in existence during the pre-Cambrian eras, such a botanical complex as the modern arctic tundra, consisting largely of lichens and mosses, may well have been in existence even at that early time.

It seems justifiable to conclude, from all these considerations, that the

pre-Cambrian history of the Medicine Bow region was not unlike the Paleozoic history of the eastern United States, in that it involved the prolonged erosion of highlands of old rocks, the accumulation of sedimentary deposits for a long time in an area of irregular subsidence, under climatic conditions that varied from arctic to tropical, and finally a period of intense compressive deformation, accompanied by the intrusion of large bodies of igneous rock and the thermal metamorphism of the sedimentary formations.

Summary

The chief results of this preliminary study of the pre-Cambrian rocks of the Medicine Bow Plateau may be summarized as follows:

1. There are twelve or more distinct formations, the stratigraphy of which has been worked out in considerable detail. The combined thickness is about 24,000 feet (not allowing for subsequent changes during deformation).

2. The formations include massive arenaceous, dolomitic, argillaceous, and pyroclastic deposits, all of which have been entirely recrystallized.

3. One of the formations contains three distinct glacial members.

4. Some of the dolomitic beds contain structures that are believed to have been made by calcareous algæ.

5. A complex of gneisses, schists, and intruded granites incloses the sedimentary formations on both sides, but its origin and its relations are as yet imperfectly known. It may be older than the sedimentary beds, but it is also possible that it is only a part of those formations, highly metamorphosed in the vicinity of large granitic intrusions.

6. The structure of the sedimentary formations is that of a northeastward-striking limb of a great anticline that is incomplete on the west side.

7. There are several steeply inclined faults, one or two of which are of large displacement.

8. Intrusions in the sedimentary formations are confined to a few small stocks of granite, many large diabasic dikes, and a rather small number of quartz and pegmatite veins.

9. The metamorphism of the rocks is believed to have taken place at moderately high temperature, but without excessive shearing.

10. The formations were probably deposited in a region of irregular depression, largely in shallow water, but partly above sealevel, under climates varying from arctic to tropical, and with relatively little contemporaneous volcanic activity.

11. The sedimentary formations are correlated with those in the Encampment and Hartville districts of Wyoming, the Red Creek district of northeast Utah, and the Willard district of the Wasatch Mountains. They are probably early Algonkian (Proterozoic) in age.

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